Semantic and form priming in fragment completion.
Evidence for subliminal activation
in a complex language-task.

Von der Fakultät für Lebenswissenschaften

der Technischen Universität Carolo-Wilhelmina

zu Braunschweig

zur Erlangung des Grades einer

Doktorin der Naturwissenschaften

(Dr. rer. nat.)

genehmigte

D i s s e r t a t i o n

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eingereicht am: 24.07.2006

mündliche Prüfung (Disputation) am: 08.12.2006

Druckjahr 2007

Vorveröffentlichungen der Dissertation

Teilergebnisse aus dieser Arbeit wurden mit Genehmigung der Fakultät für Lebenswissenschaften, vertreten durch den Mentor, in folgenden Beiträgen vorab veröffentlicht:

Tagungsbeiträge

Schütz, K. & Vorberg, D. (2004). „Semantische und orthographische Primingeffekte beim Ergänzen von Lückenwörtern“ (Poster). In D. Kerzel, V. Franz & K. Gegenfurtner (Hrsg.), *Experimentelle Psychologie. Abstracts der 46. Tagung experimentell arbeitender Psychologen*, Universität Gießen, S. 237.

Schütz, K. & Vorberg, D. (2005). „Unbewusste semantische Aktivierung bei Wortergänzungsaufgaben“ (Vortrag). In K.W. Lange, K. H. Bäuml, M. W. Greenlee, M. Hammerl & A. Zimmer (Hrsg.), *Experimentelle Psychologie. Abstracts der 47. Tagung experimentell arbeitender Psychologen*, Universität Regensburg, S. 187.

Zeitschriftenartikel

Schütz, K., Schendzielarz, I., Zwitserlood, P., & Vorberg, D. (im Druck). „Nice wor_ if you can get the wor_. Subliminal semantic and form priming in fragment completion.” *Consciousness & Cognition,* doi: 10.1016/j.concog. 2006.09.001.

Contents

Summary

The present experiments investigated subliminal semantic and form priming-effects on word-generation in a fragment-completion task. Gap-words with a dominant and a subordinate solution were preceded by form-related or by semantically related words. Compared to the exhaustively introduced lexical decisions and categorization-tasks in the field of priming research, the present task arrogates semantic processing more, because a quite complex reaction is demanded from the participants. The aim of the present study was to show that priming is observable under efficient masking, and to show that the observed effects are not based on processes apart from genuine semantic activation.

Priming of the subordinate solution was assessed in Experiments 1 and 5b, relative to a neutral prime condition. Both solutions were primed in Experiments 2-5a. Effects of word-material (e.g. word frequency) were analyzed in Experiment 3, different prime recognition tasks were contrasted in Experiments 3 and 4. In the last chapter (Experiments 5a and 5b) subliminal and supraliminal priming effects were compared, hinting at different quantity and quality of conscious as compared to unconscious priming. Influences of stimulus onset asynchrony (SOA) (Experiments 2-5b), mask duration (Experiment 2b) and shifted prime presentations (Experiment 5a) were determined, indicating no clear modulation of SOA on priming, nor an increase of the effect with shorter masks, substantiating the independency of priming from conscious processing. Shifting primes one trial back produced no clear-cut effects, though subliminal priming was observable on a descriptive level.

Essentially, semantic and form primes both reliably increased the probability with which the primed solution was given, although participants formed no conscious representation of the prime. Within this variant of fragment completion, response priming can be ruled out as explanation. Moreover, effects were already present at the first target and prime presentation, excluding an interpretation in terms of partial awareness due to repetition. The present experiments thus demonstrate automatic activation at both form and semantic levels in the absence of conscious awareness.

1. Introduction

In psychological research much effort has been put on the field of human information processing. Visual and auditory perception, as well as smell and taste, somatosensory processing and the sensation of pain are highly investigated. These fields of research are as important, as they offer deeper insight into the functioning of human information processing systems, therefore allow their imitation in engineering and lead to better medical supply whenever function is impaired.

Apart from the input side, cognitive functions manifest in action and performance, like memory, speech, attention, thinking and problem solving. The current work concentrates on two aspects of cognition: Visual information processing and word production. More precise, the present thesis investigated the role of automatic processes in perception and language production. The differentiation between automatic and controlled processes has a long standing history in psychology (Posner & Snyder, 1975). By definition, controlled processes require attention and conscious processing, whereas automatic processes should, along Posner and Snyder's criteria, occur even without conscious perception or without strong load of attentional resources.

The human cognitive system operates on several hierarchies, of which not all become subject of conscious control or conscious access. This idea becomes unsurprising when other systems, such as the motoric system are investigated. Here, automaticity is necessary for a broad range of activities, and several daily tasks illustrate the evolution of processes, which have to be performed under conscious control first and become automatic later (an often cited example is car driving, although even basic functions as walking and standing in children evolve in quite a similar way). When a motor task is learned by repetition and becomes automatic over the time, motor leaning occurs, of which a big part happens without ever reaching conscious awareness (for reviews see Schacter, 1987; Squire, 1987).

This form of learning, which occurs unintentional and without a conscious representation of the task itself, was observed in other than motor tasks as well. Reber (1967) observed implicit learning in his classical experiment on artificial grammar learning. He exposed subjects to letter strings which were governed by orderly rules (a grammar), such as DEFKLM and JKLPQR, and others which were not. The grammar itself was constructed in such a way that participants were not expected to be able to articulate the rules. Later the participants were shown further sets of letters and asked to decide which were grammatical and which not: they tended to be able to distinguish between them without knowing quite how they did it (Reber, 1967). This was taken as evidence that participants had unconsciously learned a rule, which they could not specify, and even did not know that they have learned a rule.

Thus unconscious processes are observable in learning and motor performance quite clearly. Additionally, interest has been put on the question whether unconscious processes play a role in visual perception and tasks like language production too.

By now, the fact that stimuli can be processed without a conscious representation is an acknowledged phenomenon. As is often the case in psychological research, the understanding of the intact function was helped on by observation of patients with neurological deficits. After lesions of V1, a cortical structure in the occipital lobe which processes visual information, patients develop cortical blindness, which affects the corresponding visual fields, and can even affect the whole visual field after bilateral lesions. Although all afferent inputs, as the eyes, the visual nerve and the first processing units in the brain (optic chiasm, lateral geniculate nucleus) are intact, these patients experience a complete loss of vision. Patients experience total blindness and cannot handle their environmental requirements without auxiliaries. But as was shown first in animals (Humphrey, 1974) and later in humans (Weiskrantz, 1986), subjects with V1 lesions could be trained to detect light flashes even in the affected visual fields. In his classical case study, Weiskrantz described a patient D.B., who suffered from migraine attacks and was surgically treated therefore but afterwards suffered from Hemianopsie, i.e. the loss of vision in the (left) visual field. The crucial observation of Weiskrantz was that the patient was able to detect stimuli in his defected field although he complained to see nothing in this area. Although D.B. stated that he had guessed all the time, his performance was correct in 90 percent of the time when he was instructed to decide about the orientation of a pen, presented in his hemianoptic field.

The most interesting point about this finding was the complete dissociation of subjective experience and objective performance. D.B. stated that he had guessed all the time and could not believe that his performance was that good, as is lucidly illustrated in the following dialogue between Weiskrantz and D.B. "Did you know how well you have done?" – "No, I didn’t – because I couldn’t see anything; I couldn’t see a darn thing." – "Can you say how you guessed – what it was that allowed you to say whether it was vertical or horizontal?" – "No, I could not because I did not see anything; I just don’t know", (after Weiskrantz, 1986).

To summarize, information processing and learning can certainly occur outside of conscious awareness. Yet still a lot of open questions exist as to what degree this learning occurs in every day life, or as to which degree of complexity it can be used. Can even higher cognitive functions, which exceed simple decisions or motor learning, be influenced by unconscious processed stimuli? The present doctoral thesis was done to investigate unconscious stimulus processing in the field of language production. If unconscious effects were measurable in such a complex task, this would enlarge the importance of unconscious processing, and in the same way illustrate the functioning of the human brain as working in parallel, therefore using several sources of input at once.

The following introducing sections overview the field of unconscious stimulus processing, then introduce the method of semantic priming. Models for semantic priming are presented, as well as neuropsychological findings on the field. A main focus is put on methodological issues, as unconscious stimulus processing was often investigated under weak methodological standards and was therefore criticized as being an artifact of residual awareness. Finally, the introduction gives an overview of the task used in the present work and how it accounts against the most often formulated objections against genuine subliminal semantic processing.

1.1. Unconscious information processing

As Weiskrantz' (1986) study illustrated, patient studies offered a useful hint on unconscious stimulus processing. Still, the uncommonness of isolated disorders as well as the methodological problem of confounded factors as the lesion as such made experimental manipulations necessary. A few accounts exist that made the investigation of unconscious visual processing possible. The most important account certainly is masked priming, followed by the attentional blink paradigm.

In masked priming the fact is used that stimuli can be made invisible to the observer if they are accompanied or followed by a mask, a finding first presented by Stigler (1910). Several forms of masking can be differentiated, as forward, backward, pattern or substitution masking (see Breitmeyer, 1984; Enns & DiLollo, 2000). Although no model can explain all aspects of masking, it is by now quite clear that the mask-signal interrupts the conscious representation of the target stimulus. Lamme, Zipser and Spekreijse (2003) presented an account which pronounces the role of recurrent corticocortical activations, i.e. the recurrent activation between hierarchically organized cortical structures, for the conscious stimulus representation. In his view a conscious representation necessarily relies on the crosstalk between subsequent neural structures, and this crosstalk could probably be disturbed by the mask. The masked stimulus is thus invisible to the observer if certain spatial and, more important, temporal conditions are fulfilled (Breitmeyer, 1984).

Still, the invisible stimulus can have impact on response speed and error rate. In priming research, the effect of the first stimulus (the prime) on a subsequent stimulus (the target) is investigated. If both stimuli require the same reaction (are response-congruent), faster responses and lesser errors are measured as in incongruent trials. Priming effects were observed for strongly masked primes, and indeed, seemed to depend on SOA (stimulus onset asynchrony, which defines the total amount of time the stimulus has to be processed) rather than on prime visibility (Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003). The conditions under which unconscious response priming effects occur are represented in the next section in more detail.

1.2 Unconscious response priming

Stimuli made invisible by masking can affect behavior. This has been shown in several recent studies (e.g. Dehaene et al., 1998; Klotz & Neumann, 1999; Klotz & Wolff, 1995; Neumann & Klotz, 1994). Moreover, the temporal conditions that determine the effect of a masked stimulus (‘prime’) on response speed are well understood (Vorberg et al., 2003; Mattler, 2003).

In such studies, participants react to a target, for example an arrow stimulus, pressing the left button if it points left and the right button if it points to the right. Others use numbers, with binary decisions such as larger or smaller than five, odd or even. Congruent primes map onto the same reaction as the target (for example, both prime and target are left-pointing arrows or odd numbers). Incongruent primes map onto opposite reactions. Usually, congruent primes lead to response speeding, while incongruent primes lead to response slowing, relative to a neutral prime. This form of priming is termed response priming, because the congruency effects are assumed to be based on response competition (Holender, 1992). Although semantic content of the primes was possibly processed in some studies, it cannot be ruled out that the effect is based on response activation solely.

Current work has focused on the question what kind of information can be processed unconsciously. The question arose how smart the unconscious is. Apparently not only simple features of the prime can be processed, but also conjunctions (Vorberg, in prep) of two stimulus attributes. Moreover, recent studies have shown that temporal and spatial attention can have influence on the prime’s impact too (Kiefer & Brendel, in press; Naccache, Blandin, & Dehaene, 2002). Contrary to the definition for automaticity from Posner and Snyder (1975), which states that automatic processing is capacity free, attention seemed to modulate the observed priming effects.

Direct parameter specification offers a framework for response priming (Neumann, 1989). In Neumann’s account, primes can influence behavior if they fit into the planned actions of the participant. Given that a prime contains several features (e.g. size, parity, form or color), the action plan (e.g. react with a left button press on a number if it is smaller than five) defines which dimension (or combination of dimensions) has to be reacted on. The assumption of an action plan explains which stimulus attributes of the prime are processed, and why priming effects can change if the task changes. However, some priming effects seem to operate more automatically, as primes can show influence on target processing even if they were not integrated into the actual action plan (Vorberg, in prep).

Taken together, response priming research has shown that masked primes can be processed unconsciously, in a flexible, task-adapted way. The observed effects are fast acting and seem to grow (except for long SOA-conditions with an additional stimulus between prime and target, where effects actually inverse, Schlaghecken & Eimer, 2002; Lingnau & Vorberg, 2005) almost linearly with the total processing time of the prime (SOA). In the first 100 ms of prime processing, no differences to conscious processing exist (Vorberg et al., 2003). This finding is in line with neurophysiological models, which emphasize on the role of the first processing sweep (Lamme et al., 2003), which is the same for conscious as well as unconscious processed stimuli. The next section focuses on semantic priming and describes differences and similarities to response priming.

1.3 Semantic priming: Basic findings and implications

Similar to response priming, in semantic priming the influence of a preceding stimulus (the prime) on the reaction to a target is investigated. The phenomenon that responses to words are facilitated when preceded by semantically related words, has been used extensively to investigate language processing and semantic memory. Both, masked and visible semantic priming effects are investigated in the field.

The most important difference to response priming lies in the assumption that the semantic prime activates its lexical content (in semantics, morphology, orthography or phonology), not simply its related response. However, the possibility that response priming could be the cause of the effect is one of the most important objections brought up against the existence of genuine subliminal semantic priming. This point is addressed in further detail later. Other differences to response priming lie in the masking procedure (mostly pattern masking) and the longer SOA-frames introduced in semantic priming.

A typical trial in semantic priming studies consists of a target word, which has to be reacted to, preceded by a prime word, for which usually no response is required. Common tasks used are lexical decision, pronunciation, and categorization. The robust and often replicated finding is facilitated target processing after related as compared to neutral or unrelated primes (for a review see Neely, 1991; Neely & Kahan, 2001; Dehaene et al., 1998; Dehaene et al., 2004; Greenwald, Draine & Abrams, 1996).

Unconscious activation has also been reported with semantic priming proper (Greenwald et al., 1996; Draine, 1998; Abrams, Klinger & Greenwald, 2002; Kiefer & Spitzer, 2000; Kiefer, 2002). Abrams et al. (2002) used a pleasant-unpleasant classification task and showed priming effects of visually masked semantic primes within. At the beginning of their experiment, prime words were presented non-masked as targets which had to be classified. However, the observed effects were still measurable when response mapping was reversed between practice and priming blocks. Abrams et al. (2002) interpreted this finding as evidence for the assumption that practice establishes word-to-category rather than word-to-response mappings. This finding offers an alternative explanation for the frequent observation of stronger priming effects of practiced compared to small if at all measurable effects from unpractised primes.

Kiefer (2002) showed reliable masked semantic priming within a lexical decision task, both on response times and the N400. In his design, a semantic prime reduced the time participants needed to decide if a target stimulus was a word or non-word. This benefit was uncorrelated with the particular performance of the participants in a subsequent prime recognition task.

Draine and Greenwald (1998) provided evidence for subliminal semantic priming in a word classification task (male-female, pleasant-unpleasant classification). The authors introduced a response window procedure which allowed analysing the data with a regression method (Greenwald, Klinger, & Schuh, 1995). Under certain assumptions, the direct and indirect effect can be compared therein, as both priming and discrimination are focused on the performance dimension of accuracy rather than on speed.

Greenwald et al. (1996) investigated markers of unconscious semantic activation with the response window procedure in a word-classification task. Apart from the observed effect the prime showed on pleasant-unpleasant classifications, the authors showed that contrary to supraliminal priming, subliminal semantic priming attenuated with longer SOAs, additionally, no trial-to-trial modulations were observed in the subliminal processing mode, whereas sequential modulations were observed for consciously processed primes. However the supraliminal primes were presented with longer SOAs, thus, this finding might have also been due to the confounded SOA.

These studies suggest that not only motor responses can be triggered via an unconscious route, but also associations and semantic relatives. In the spreading activation tradition (c.f. Collins & Loftus, 1975), it is assumed that an unconsciously processed prime can activate a network of representations of related words/concepts. If a target word belongs to this network, the preactivation by the prime facilitates its processing. Subliminal effects can also be explained by distributed memory models (Cree, McRae, & McNorgan, 1999; Plaut, 1995) or by compound cue models (Ratcliff & McKoon, 1988). The competing accounts are introduced in more detail in the following sections.

1.4 Contrasting semantic from associative priming

Apart from the question whether semantic priming can occur without conscious awareness, an important line of research investigates the question whether semantic priming can occur without association (Lucas, 2000). Associations can exist without semantic overlap (e.g. dog - cat), and semantic overlap can be quite strong without a strong associative relation (bus - subway) as well. On which relation the observed (supra- and subliminal) priming effects depend is of importance, as it gives insight into the structure of underlying networks and the validity of supposed models. Additionally, the question is investigated which form of priming (associative or semantic) is faster and more automated (Bueno & Frenck-Mestre, 2002).

In a meta-analysis of 26 studies, Lucas (2000) investigated the question, whether semantic priming can occur without association. In the earlier studies of semantic priming (Meyer & Schvaneveldt, 1971), semantic priming was actually associative priming, as prime-target pairs were drawn from word association norms. The attempt to unconfound both mechanisms led to mixed results and to a controversy about the existence of purely semantic priming (Lucas, 2000).

In order to clear up this issue, the author concentrates on non-masked priming and included priming tasks like lexical decision, naming and the Stroop task only. The main finding was that semantic priming can be reliably found without association, that it can occur automatic and that an associative relationship boosts the effect. In fact, adding association to a semantic relationship roughly doubled the effect size found.

Bueno and Frenck-Mestre (2002) investigated semantic and associative priming effects too, but investigated the effects of masked primes. They used a semantic classification task, that is, targets had to be classified as being either a concrete or an abstract word. Targets were preceded by a masked prime, which could either be a synonym, thus sharing the word meaning of the target, or a 'first associate', thus a word which can probably trigger the target word (the associated primes were constructed along published association norms). Bueno & Frenck-Mestre found priming effects for both sorts of primes, but with differing time courses. Whereas the synonym priming was observable from the first prime duration (43 ms) on, the associative prime showed significant priming for longer prime duration only (the effect started at 57 ms and increased at 70 ms). Although visibility differences existed between the different prime durations (increased prime visibility with increased prime duration), prime category had thus a dissociable effect. The authors concluded that this difference was due to the smaller semantic distance synonyms had to targets than associates had.

These findings supported distributed connectionist models, which assumed that concepts have activation patterns made up of semantic features (Cree, McRae & McNorgen, 1999). When concepts are semantically close, their patterns resemble each other, and the transit from one to the other becomes faster. Because synonyms should have more similar activation patterns than associates, their effect should occur faster and earlier, as was indeed demonstrated by Bueno and Frenck-Mestre (2002). Still, the associates showed strong priming effects too, given a necessarily long prime duration. The authors interpreted this in terms of increased visibility of primes. In their view, semantic priming can occur automatically, but the associative priming requires conscious processing. However evident this conclusion may seem, it has a possible alternative: Priming effects critically depend on SOA, which can be manipulated independently of visibility (Vorberg et al., 2003). Therefore it is possible that associative priming occurs with longer SOA, even without higher visibility. This question cannot be answered with the data of Bueno and Frenck-Mestre, as they did not vary SOA independently of prime duration. Assuming that SOA would explain the effect, the model should manage to describe the results without assuming different processes for visible and invisible stimuli.

In an earlier experiment (Frenck-Mestre & Bueno, 1999), the authors found a quite similar pattern of results. Semantic nonassociative pairs showed earlier facilitation than did associative-semantic pairs. Taken together their findings, associative priming seems to take longer than semantic priming to occur, even though the question has to be investigated, whether visibility differences or differences in SOA solely cause this effect.

The results of Bueno and Frenck-Mestre (2002) are not contrary to the findings of Lucas (2000) however. In Bueno and Frenck-Mestre’s (2002) experiment, associative priming increased and even exceeded semantic priming with longer prime duration (and longer SOA). Since Lucas (2000) analyzed supraliminal priming, the prime durations and therefore SOAs were rather long, and therefore advantageous for associative priming. For the present work it is of importance that semantic priming can occur without association and that it is probably faster acting than associative priming. When masked associative priming is investigated, it should be secured that SOAs at least over 70 ms are used, the duration found necessary by Bueno and Frenck-Mestre (2002).

1.5 Automatic semantic priming

A main question in the field of semantic priming is whether the observed processes are automatic or controlled, or both. In a review of 2001, Neely and Kahan pooled the findings of research along four criteria for automatic processes, formerly postulated by Posner and Snyder (1975). The criteria of an automatic process in this account were that it is [... (a) fast acting, (b) is capacity free, (c) can occur without intention, (d) is involuntary or uncontrollable, and (e) can occur without conscious awareness, Neely & Kahan, 2001, pp. 69]. Discussing several sometimes contrary findings, Neely and Kahan (2001) came to the conclusion that semantic priming can in fact occur without intention and is not affected by the amount and quality of the allocated attentional resources. Meanwhile, spatial attention was a necessary condition for semantic priming to occur, which suggests that the underlying processes operate not qualitatively different to controlled processes, as they need features and their integration too.

This finding was important as it is contrary to a demand proposed by several authors in the filed, who long for dissociations between automatic (subliminal) and controlled (supraliminal) processes (e.g. Holender & Duscherer, 2004). In these authors view, a real subliminal automatic process should be qualitatively different from a controlled process; otherwise it would not represent subliminal perception but 'weak' supraliminal perception. The account of Lamme et al. (2003) made this demand improbable. Lamme et al. (2003) reported neurological evidence for the fact that conscious and unconscious processes are based on the same neural structures. In his account, conscious and unconscious activation do not differ while entering the system (e.g. the visual cortex), but differ in the following processing steps. Lamme et al. assume that for any conscious representation of a stimulus, recurrent activation is necessary. Without the temporal fit of the neural code on higher and lower processing levels, no conscious representation can be formed. Thus in a model according to Lamme et al.'s, automatic processing should not differ in basic recommendations as spatial attention on the stimulus.

Subliminal semantic priming offers an excellent account to test several of the criteria of automaticity at once. If real subliminal semantic priming would be observable, almost all of the criteria would be fulfilled and the conclusion that semantics relies to a strong degree on automatic processes would have another strong pro.

In a recent paper by Kiefer and Brendel (in press), subliminal priming in a lexical decision task was shown to be sensitive to temporal attention, modulated by a cue. The observed attentional modulation was solely observed in the N400 priming, not in the behavioral data, a finding which is not fully understood yet.

1.6 Semantic and form priming in word completion tasks

Word-completion tasks are frequently used in studies on implicit memory (Graf & Schacter, 1985; Squire, Shimanura, & Graf, 1985; Mayes & Gooding, 1989), as well as in priming experiments (Roediger & Blaxton, 1987; Kroll, Rocha, Yonelinos, & Baynes, 2001). Usually, in word-completion tasks (Debner & Jacoby, 1994; Hutchison, Neely, Neill, & Walker, 2004), participants have to complete the stem of a word (e.g., elastic; ela___), which is preceded by a prime word.

Some authors (Forster, Booker, Schacter & Davis, 1990; Debner & Jacoby, 1994) found that a prime increased the likelihood of its being given as a solution. In the Debner and Jacoby study (1994), this priming effect was indeed subliminal, as the authors used process dissociation to show the unconscious proportion of the effect.

However, this finding has not necessarily to be due to subliminal semantic priming. Alternatively, the effects could be due to sublexical processes (Hutchison et al., 2004), because prime and target shared the same visual features, as they were identical or form-related. Hutchison et al. (2004) showed that the observed effects can be accounted for by sublexical effects and that the additional semantic content of a repetition-prime does not lead to additional priming effects compared to a form-prime. This interpretation is compelling but controversial at the same time. Alternatively to the interpretation of Hutchison et al., the semantic content of the repetition prime might have been processed subliminally, but the form-priming effect might have been stronger and thus might have superimposed the semantic effect. This question can only be resolved when form-primes are compared with semantic primes which do not share critical visual features of the target. Similar to the described logic of semantic priming, form priming involves the presentation of prime-target pairs that are orthographically and/or phonologically similar (cf. Kinoshita & Lupker, 2003; Zwitserlood, 1996). With words or word fragments as targets, form primes have been reliably shown to ease their processing.

Two variants of form priming are investigated most often: Direct and mediated form priming. In direct from priming, prime and target are related; in mediated priming, the target is semantically related to a word which is form related to the prime. The form-relatedness is characterized by the overlap between prime and target, which can vary from one to all letters. The tasks used are, similar as in semantic priming, mostly lexical decisions or naming, and to a lesser extent identification in noise, or Stroop-like tasks. The finding of facilitated target processing has been found for different sources of overlap, as initial- and rhyme-overlap (see Zwitserlood, 1996, for a review). Zwitserlood (1996) summarizes that word-fragments lead to facilitation in unimodal priming, and that word-in-word pairs lead to facilitation only when very long SOAs are used. The found effects are located on a lexical level most likely, a position which is substantiated by the results of mediated form priming studies, where the activation of the target necessarily includes the activation of its semantic associate (e.g. “other” activates “mother” which activates “child” that serves as target). The degree to which the reported effects occur automatically remains somewhat unclear, as automaticity is highly dependent on temporal parameters like SOA and ISI (Neely & Kahan, 2001), the tasks used, and the proportion of related trials. To show masked form priming in the present work thus would further corroborate the existences of an automatic component in form-priming.

To summarize, word-completion tasks offer the opportunity to investigate subliminal influences on word-generation. The investigated response is a word, not a button press, which offers the advantage that the observed effects cannot be due to response activation. However, many solutions are possible when completing word-stems and therefore many confounding variables might play a role. Thus, the method might not be very sensitive to the small and short-living subliminal effects. The present work’s attempt was to combine the advantages of word-stem completion, with the higher power of a more restricted task. This account is presented in Chapter 1.10.1 in detail.

1.7 Theories on semantic priming

1.7.1. Spreading activation

The first to formulate a theory of spreading-activation of human semantic processing was Quillian in 1962. His model was developed further by Collins and Loftus (1975), who showed how several empirical results could be integrated in the model. Since then, the spreading activation account remained useful, often cited in explanations of language processing as well as memory functions (Anderson, 1983; McNamara & Altarriba, 1988).

Basically, the theory assumes that concepts, which can be words or sentences (and their corresponding qualities), are represented as nodes in a network (i.e. the human brain). Properties of a concept are labeled links from node to node. The strength of a link between two nodes can differ, which is represented by a factor or weight, a quality Quillian named criteriality. As Collins and Loftus (1975) pointed out in their classical work, priming can be well explained in terms of spreading activation: They argue that “priming (or preparation) involves the same tracing process (…) (as) memory search” (p. 409). Accordingly, links (the properties) as well as nodes (the concepts) can activate each other in the network, albeit leading to facilitated reactions on the following stimulus. To conclude, the spreading activation theory offers a useful account whenever successive processing steps are eased by a semantic interrelation of the to-be-processed stimuli.

1.7.2. Distributed memory models

Distributed memory models developed the spreading activation approach further. The basic assumption of these models is that concepts have activation patterns made up of semantic features (Cree, McRae & McNorgan, 1999; Plaut, 1995). These patterns are mapped in distributed connectionist networks. In contrast to the spreading activation account, each concept is represented, not by a particular unit, but by a particular pattern of activity over a large number of processing units. Each unit represents a semantic feature which participates in many concepts. In difference to spreading activation, these features are abstract, not necessarily verbalizeable attributes of the concepts.

Simulations with connectionist networks (Plaut, 1995) could account for a wide range of empirical findings in semantic and associative priming. Most interestingly, they even modeled the different effects observed for semantic and associative priming. Plaut (1995) assumed that the different time courses of semantic and associative priming (weaker semantic and stronger associative priming with longer SOA) were due to the differing representations of prime and target which manifest in the network over time. The activation pattern of a prime first is similar to that of the target, consequentially, target processing benefits. As processing time goes on with longer SOA, the representations become more differentiated, thus the represented patterns of primes and targets differ more and more with ongoing time. In associative priming, the effect is assumed to be due to a different mechanism, the learned connection of prime and target. In associative priming, Plaut (1995) followed eased retrieval with longer prime-target asynchrony, thus stronger priming for long SOA conditions, which is in fact the finding often reported in literature (Shelton & Martin, 1992; Bueno & Frenck-Mestre, 2002).

1.7.3. Compound-cue theory

As an alternative to the models in the spreading activation tradition, Ratcliff and McKoon (1988) presented the compound cue theory. Basically the theory assumes that facilitated target processing, as observed in priming, can be explained by the combination of the prime and target into a compound-cue.

Based on the Gillund and Shiffrin (1984) model, Ratcliff and McKoon (1988) assumed that long-term memory is composed of images. At encoding, items enter a short-term buffer (i.e. short-term memory), their relations strengthen over time and finally, each cue item is related to each image in memory. This relation differs in strength with the degree of connection between cue and image (with high connection for cues and images which were rehearsed together), thus resulting in stronger connections and more residual ones.

In this model, priming can be explained as follows: “For priming, when a prime is presented preceding a target item, then the two items are assumed to form the compound cue (along with context).” [Ratcliff & McKoon, 1988, p.388]. The consequence of this assumption is quite similar to the predictions of spreading activation: The more connected two concepts are in memory, the greater the familiarity and the faster the reaction to the target. Following the model, priming effects are observed if the compound-cue has high familiarity. Familiarity is based on the connection strength between the items in long tem memory and on their coexistence in the short-term buffer. According to the model, higher familiarity is linked to shorter reaction time and higher accuracy. In spreading activation, a temporary activation of the long-term memory system is incorporated, whereas in the compound-cue theory, long-term memory is not involved.

In Ratcliff and McKoon’s (1988) view, many findings in priming research could be better explained by the compound-cue theory (e.g. decay of priming, backward priming, onset of priming) than by the spreading-activation account. However, by now it has come to no decision between the concurring models. Spreading activation theory (Collins & Loftus, 1975), distributed memory models (e.g. Plaut, 1995), and the compound-cue model (Ratcliff & McKoon, 1988) can all explain subliminal semantic effects.

For the present work it is of importance that in the compound-cue theory, familiarity, and therefore the strength of priming, is determined by associations in long-term memory. These associations can be existing ones (from the subjects’ lexicon) or newly learned ones (as in Ratcliff & McKoon, 1981). It follows that the priming effects should strengthen in the course of the experiment when prime-target pairs are repeated and the association between prime and target becomes stronger. The present experiments will focus on the influence of repeated prime-target pairs on the magnitude of priming.

1.8 Neuronal correlates of semantic priming

Since behavioral evidence is in line with an automatic activation account, the question intrudes which neurophysiological structures are involved in subliminal semantic activation. Two methodological accounts dominate the research: Event related potentials (ERPs) and functional magnetic resonance imaging (fMRI). Both can be used to investigate the neurophysiological correlates of conscious and unconscious processes only partially.

ERPs are a specific component of electroencephalography (EEG). They are extracted from the spontaneous EEG and reflect systematic answers of the brain, which precede an event, accompany it, or follow on from it. Differentiating variables are the amplitude and time window of these answers. By now, several ERP components have been linked to specific individual processing. Sensory processing, mental processes, movement planning and executive functions have been associated with specific deflections of the ERP to a defined time-window (Squires, Wickens, Squires, & Donchin, 1976; Donchin, 1979). One such component is the N400, a negative ERP deflection over the centro-parietal scalp at around 400 ms after stimulus presentation. This component reflects semantic processing (Kutas & Hillyard, 1980), and is sensitive to semantic incongruities and errors, both at word and sentence level (e.g. Bentin, McCarthy, & Wood, 1985; Friederici, Hahne, & Mecklinger, 1996). The N400 is also sensitive to semantic priming whereby targets which are preceded by a semantic prime evoke a smaller negative deflection than targets which are combined with a neutral prime (Kiefer, 2002; Kiefer & Spitzer, 2000). This N400 priming effect was consistently observed in tasks with visible, non-masked primes (Kutas & Hillyard, 1980), whereas the situation for masked primes is less clear cut.

Some experiments showed that although reliable behavioral priming was apparent for non-masked as well as for masked primes, N400 priming was observed for visible primes only (Brown & Hagoort, 1993). Contrary to these findings, Kiefer (2002) showed that N400 priming is observable for completely masked primes too, and offered an account to resolve the dilemma (Kiefer & Brendel, in press). In the authors' view, stimulus onset asynchrony (SOA) has to stay below a certain value, and, even more important, temporal attention to the prime is a prerequisite for N400 priming on masked, invisible primes to occur. Taken together, the N400 can reflect semantic priming for masked as well as non-masked primes, given that temporal and attentional conditions make prime processing possible.

Put more simply, the system has to have at least the chance to process the prime up to a certain degree. In line with the ideas of Enns and DiLollo (2000) and Lamme et al. (2003), prime processing does not reach participants' awareness because the representation of the prime is not connected between different processing steps. Lamme et al. (2003) reported neurological evidence for the fact that conscious and unconscious processes are based on the same neural structures. In his account, conscious and unconscious activation do not differ while entering the system (e.g. the primary visual cortex (V1)), but differ in the following processing steps. He assumes that for any conscious representation of a stimulus, recurrent activation is necessary. Without the temporal fit of the neural code on higher and lower processing levels, no conscious representation can be formed. Quite similar ideas were proposed by Enns and DiLollo (2000), who stated that masking, which renders the prime stimulus out of conscious awareness, relies on the same phenomenon: Whilst entering higher levels of processing, the representation of the prime in V1 is already overwritten by the mask, the crosstalk between the two representation sites is thus not possible, masking occurs, and the prime does not reach subjects awareness.

The second major approach studying the possible neuronal correlates of semantic priming is fMRI. Although the method has disadvantages in temporal resolution, it was introduced in the field of semantic priming. The authors using fMRI followed a comparable logic to ERP-research: After a semantic or orthographic activation of the prime, target processing should be modified or at least influenced, as it is apparent in RT and ERP effects. Equivalent effects should be measurable with fMRI too. Different haemodynamic responses to the target are assumed to depend on the relation between prime and target, and therefore should reflect the priming effect itself.

Dehaene et al. (1998) studied the effects of masked primes with both fMRI and ERP. They used a numerical decision task (participants had to decide whether a number was smaller or bigger than five), and were especially interested in the neuronal substrate of the behavioral priming effect, which was about 20 ms. Importantly, discrimination performance was at chance level, with *d'*, a measure of discrimination performance, not reliably different from zero.

Two findings were of interest: A significant modulation of a specific ERP component was measurable, the lateralized readiness potential (LRP) that indexes the activation of lateralized motor circuits. The LRP clearly indicated a motor preparation on the incorrect side of response on incongruent trials, a finding perfectly in line with increased error rates and higher RTs on incongruent trials. This result was mirrored in the fMRI data. A positive peak over the left and right motor cortices following each motor response; the lateralized bold response (LBR), was prime sensitive too. In fact this signal was dependent on prime congruency, smaller after incongruent trials.

In a newer study, Dehaene et al. (2004) used words as primes and targets and were specifically interested in the left fusiform gyrus, a structure which contains the visual word-form area (VWFA), a region specifically involved in visual word processing. Earlier research (Dehaene et al., 2001) had shown that the activation in the VWFA dropped, when the target was preceded by a masked prime. Thus fMRI showed a repetition priming effect analogously to the N400 modulation described above. In the new study, Dehaene et al. (2004) were specifically interested in the nature of this priming effect. To test on what features the VWFA-priming was based on, different clusters of primes were used.

In Experiment 1 prime-target pairs were cross-case with dissimilar shapes (R-r). In Experiment 2, circular anagrams were used, i.e. words that were shifted in one letter from front to back and this way constituted a different word in meaning. The main goal was to show if VWFA-priming was based on single features or on larger constituents of words. Both behavioral data and neuroimaging data showed that the priming effect was case invariant, the VWFA activation, especially in the left VWFA, was smaller after repeated primes even if they consisted of dissimilar letters and thus looked differentially. The second experiment showed that behavioral priming depended exclusively on a location invariant representation of the whole word, thus no priming of anagrams occurred. The VWFA-priming was less clear-cut, as several subdivisions of the fusiform region could be separated, some reacting on shifted repetitions, others not. Dehaene et al. (2004) argued that their findings speak for the view that at least some units of the fusiform gyrus react on invariant aspects of word processing. The authors assumed that several brain areas are engaged in masked priming, and that fusiform gyrus is one of them, with the described properties.

Another experiment also using fMRI was done by Copland et al. (2003). The authors investigated different prime-target relations on lexical decision. Primes and targets could be dominantly related, subordinately related or neutral to each other. The dominant and subordinate relations were constructed due to the fact that primes in the study were ambiguous words (words with more than one independent meaning, e.g. bank). As primes had two meanings, one dominant and one subordinate, the subsequent target could be related to one of them. Thus, Copland et al. (2003) hoped to find different activation patterns in accordance to the strength of activation for targets. The authors predicted reduced cerebral activation in the fMRI signal associated with related word pairs compared to unrelated pairs.

Indeed, Copland et al. found a reduced BOLD signal in the left middle temporal gyrus and the left inferior prefrontal cortex after related prime-target pairs compared to unrelated pairs. These effects were accompanied by a behavioral priming effect of 52 ms in the dominant and of 30 ms in the subordinate condition. However, a direct comparison of the priming related BOLD signal changes revealed no difference between the dominant and subordinate condition. Although no masking procedure was introduced, Copland et al. interpret the observed priming effects as automatic semantic priming, because of the short SOA between prime and target. Furthermore, the authors argue that the facilitation for both dominant and subordinate related conditions is consistent with modular models of word recognition that hold that all meanings of a word are activated while entering the system. Only after this initial stage, attention is directed toward one single meaning (Simpson, 1984). Consequently, Copland et al. interpreted that the middle temporal and the left inferior prefrontal cortex were involved in automatic aspects of semantic processing.

These findings suggest that both fMRI- and ERP-modulations can be obtained through semantic priming. However, the N400 modulation not necessarily reflects semantic activation on word-level. This hypothesis became probable by results of Holcomb (1993). He showed that N400 and RT priming reflect at least two different processes. Holcomb (1993) degraded the stimulus words in his experiment, which led to reduced priming on RT, but not on N400 level. The author interpreted this finding, in that the N400 might reflect a post-word level process, not a word-level process. Spreading activation, in contrast is thought to operate on word-level.

Moreover, Deacon, Dynowska, Ritter and Grose-Fifer (2004), as well as Radeau, Besson, Fontenau and Castro (1998) have shown that the N400 modulation is also observable after phonologically related (Radeau et al.) and non-word primes (Deacon et al.). In the Deacon study, two sets of nonword primes were investigated, non-words which were constructed on a real root word and non-words which had no root word. Both were pronounceable and orthographically legal. The interesting result was that the N400 modulation occurred after the non-words which were not rooted in a real word too. Apparently, the N400 reflected a process not exclusively relying on semantics here.

This result is noticeable, although the study operated with non-masked primes. The typically found N400 modulation for masked primes is not qualitatively, but rather quantitatively different to the one observed for non-masked primes. Thus, although a N400 modulation can occur after semantically related primes, this modulation is not restricted to reflect semantic activation alone, but might reflect a later, post word-level process, which also acts for non-words and orthographical/phonological relations. This process can act automatically and out of consciousness, but is no direct proof for the spreading activation account, which is thought to operate on word-level.

Altogether, the N400 priming effects (Kiefer & Spitzer, 2000) as well as the observed modulations of the BOLD signal (Copland, 2003) reflect a fast acting, facilitating process, which is probably independent of word-form (Dehaene et al., 2004). However, the interpretation of the underlying process as a genuine automatic semantic one is criticizable, as consciously controlled processes cannot be ruled out in most experiments (like in the experiment of Copland et al., 2003). This and other objections against unconscious semantic activation are presented in the next section in greater detail.

1.9 Objections against genuine subliminal semantic priming

The existence of subliminal semantic priming has ever since the findings of Greenwald and Draine (1998), and Dehaene et al. (1998) been criticized. Four major objections have been made against genuine subliminal semantic processing:

First, it was questioned whether the observed effects were truly unconscious. Holender and Duscherer (2004), as well as Kouider and Dupoux (2004) stressed that the semantic effects could be based on partial awareness of the primes by some participants in some trials. This argument was based on the fact that discrimination performance (*d'*) fluctuated around zero in most studies and was thus not at chance level for all participants (Holender & Duscherer, 2004) and on the finding that participants performed better on partial- than on global-awareness tests (Kouider & Dupoux, 2004). Although participants were not able to discriminate complete words, they could see fragments of the words. Kouider and Dupoux concluded that a suitable paradigm should produce reliable priming effects without massively repeating the prime stimuli, as is indeed often the case, in particular, when category names are used as primes. Thus the question arises whether evidence for subliminal semantic priming still remains if primes are presented only once in the experiment, never occur in the target set, and are never consciously processed.

Second, it was questioned whether response priming could explain the observed effects (Holender, 1992; Damian, 2001; Klinger, Burton, & Pitts, 2001; Holender & Duscherer, 2004). The authors described that in the major part of all studies demonstrating masked semantic priming, repeated prime-target pairs (or repetition-priming designs) were used, combined with two-alternative forced choice tasks (e.g. lexical decision, evaluation, categorization). In these experimental setups it is quite plausible that the prime is associated with its according response. The facilitating effect would thus be due to response priming, not to an automatic activation of represented language. Abrams et al. (2002) argued against response-priming accounts of priming in word classification, and claimed that word-to-category mappings rather than word-to-response mappings were the basis of these effects. Further empirical support for this position has been reported recently by Klauer, Eder, Greenwald, and Abrams (in press). However, the reversal of response assignments, as was implemented in the study of Abrams et al. (2002) between practice- and test-phase, does not necessarily defuse this objection, as the according response mappings could be represented on a higher, more abstract level.

Third, sublexical processing (Hutchison et al., 2004) was taken as an alternative explanation for the effects observed. The authors showed that the orthographic or phonological overlap alone could completely account for unconscious identity priming. This argument was important for the interpretation of those experiments working with repetition priming (e.g. Masson, 2002). Especially in these setups, masked words may only activate their sublexical representations, but not their lexical ones.

Finally, related to the second objection, it has been criticized by some authors (e.g. Bueno and Frenck-Mestre, 2002) that the reduction on two response dimensions (as for example in lexical decision tasks) in a field as complex as language production is a rather artificial one. Although the lexical decision task has a long standing tradition in psycholinguistics, evidence for subliminal semantic priming should be observable with other methods too, given that the effects are based on true semantic activation, not on response activation.

1.10 Open questions

While unconscious response priming is by now an acknowledged phenomenon, two different camps still argue about the existence of unconscious semantic priming. As presented in the preceding section, reasonable doubt has been formulated against the assumption of an unconsciously operating activation-system in human language processing. However, inspections of impaired function or daily experiences like slips of the tongue give strong naïve evidence for a process which operates outside of conscious control. The present research therefore concentrated on experimental issues to eliminate the methodological traps. Meanwhile, the strict separation between conscious and unconscious processing is considered too, as current approaches consider both processes working on one dimension, not on dissociable ones.

1.10.1 Own account

The experiments presented in the following are designed to answer the so far depicted methodological and theoretical questions. Furthermore, an approach is tested, which combines advantages of different experimental setups. The present task avoids the objections introduced in Chapter 1.9, and offers a method to investigate word generation in an economic fashion and with a rather complex approach: word- or fragment-completion.

The described accounts like lexical decision, pronunciation and categorization have not least been used so often because they measure priming effects economically and with small error-variance. The present work tried to combine the advantages of both accounts.

Therefore, a variant of the word-completion task was used, in which participants had to complete words with one letter missing (gap-words). The gap-words were constructed such that two solution words were possible, one dominant, the other subordinate. I hypothesized that a masked prime should enhance the probability of its related solution, thus a subordinate solution should become more frequent, and a dominant even most frequent, than after a neutral prime. Both semantic and formal prime-target relations were investigated to be able to estimate the proportions each route of activation has on priming.

In Chapter 2 (Experiment 1), the basic approach is introduced in detail. The construction of the material and description of a pretest is documented. The third chapter (Experiments 2a and 2b) investigates priming effects of both dominant and subordinate solutions and variations of temporal parameters as SOA and mask durations. Importantly, a prime recognition task is introduced.

In the present work, recognition tasks are implanted which are most similar to the experimental setting, solely differing in the attentional focus and specific task for the participants. In all details concerning visibility of the prime stimulus, the recognition task is unaltered: Prime duration, SOA and masking procedure are identical. Since the target is seeking attention in the priming task too, it is also presented in the recognition tasks, but subjects have to focus on the prime. The proper task of the subjects had to be varied, because, as the prime was no gap-word, it did not permit the same reaction as the target and could not be completed. To avoid this obvious limitation in comparability, I used two different recognition tasks, with the intention to discriminate automatic, unconscious effects of the prime from conscious, explicit ones.

In Experiments 2a, 2b and 3 an inclusion-exclusion account (Debner & Jacoby, 1994) is introduced, which forced participants to alter their response strategies. In Experiments 4, 5a and 5b, a forced-choice measure of prime recognition is presented, invented to minimize the automatic activation of the prime on the direct task.

A target-wise analysis is presented in Chapter 4 (Experiment 3), to clarify whether the observed priming effects are observable for most or only a fraction of gap-words, and to control other potential effects of word-material. Finally, Chapter 6 (Experiments 5a and 5b) contrasts masked with non-masked priming, to show how conscious and unconscious activation differ, and to show if dissociations are observable between both modes.

If priming effects were measurable, the paradigm offered a strong advantage: the three major objections against genuine semantic priming could be addressed with the results.

(1) Response priming? If priming effects are seen, they cannot be attributed to response-priming mechanisms, because response alternatives change from trial-to-trial and targets imply no response-mapping. Thus priming effects in the present paradigm have to on real semantic activation, not on response activation. (2) Prime visibility? The extent to which prime-processing was indeed unconscious was measured. Prime and target repetition was controlled in all experiments; moreover primes never occurred in the target-set. (3) Sublexical activation? To control for sublexical influences, semantic primes were contrasted with from-primes. If a semantic effect remained, it would not be accountable for by sublexical influences.

To subsume, the questions and hypotheses of the present work can be summarized as follows:

I. Is subliminal semantic priming a real phenomenon or an artefact? Can subliminal semantic priming effects be measured in a complex task like word-generation?

Priming effects are expected to manifest in higher probabilities for primed solutions. These priming effects are assumed to occur with the first presentation and under strong masking conditions, and are thus assumed to be based on automatic processes, not on learned connections.

➢ This question is investigated in Experiments 1 - 5.

II. Which prime recognition-task is best to differentiate automatic from conscious controlled effects? Is priming strength dependent on conscious prime representation?

Recognition performance is hypothesized to on two factors, the conscious representation of the prime-word as well as on the automatic activation of the prime. These factors should be distinguishable with tasks that vary the degree of usability of this activation.

➢ This question is investigated in Experiments 2 - 4.

III. Are priming effects equally strong for all solutions, or are only subordinate or dominant solutions susceptible for priming? Depend the observed effects on word frequency? Are some gap-words stronger influenced than others? Is priming dependent on the dominance-degree of solutions, thus are only those solutions modifiable which are rather close in spontaneous completion frequency (e.g. 60:40)?

If based on automatic semantic activation, word-frequency should not interact with the priming effect (Bueno & Frenck-Mestre, 2002). Priming should be observable for the major part of targets. The degree of dominance of a solution might influence the strength of the effect, with stronger effects for likelier solutions. Likewise, even solution-pairs with extremely differing probability should be modifiable, if the masked prime activated their particular representational networks.

➢ These questions are investigated in Experiment 3.

IV. Are form-priming effects stronger than semantic effects? Are the time-courses for both comparable?

Controversial hypotheses are possible for the dependency of semantic priming effects on SOA. Greenwald et al. (1996) found decreased semantic priming with longer SOA, whereas response priming has been reliably shown to increase with longer SOA (Vorberg et al., 2003). Form primes are expected to be rather fast acting, so no strong dependency on SOA is expected in the investigated time-range. Form priming effects are expected be overall stronger than semantic priming effects.

- These questions are investigated in Experiments 2 - 4.

V. Do supra- and subliminal priming effects differ quantitatively or qualitatively? Where is the maximum priming effect with perfectly discriminable primes located?

Stronger priming for visible than for invisible primes is expected. No qualitative differences are anticipated.

- This question is investigated in Experiments 5a and 5b.

In combining these questions, masked semantic priming will be systematically investigated to substance and limits. The combination of results is therefore of relevance.

2. Experiment 1: Priming the subordinate solution

The aim of Experiment 1 was to demonstrate masked priming in a word completion task with two response alternatives. The hypothesis was that the weaker of the two solutions would be produced more often when preceded by a semantic- or form-related prime. Semantic and form similarities were manipulated to investigate whether priming is observable after form primes only, or could actually be produced by semantic similarity, for which form-overlap was excluded. Masked semantic priming would speak for effects on a lexical level, a possibility often posed into question (e.g. Hutchinson et al., 2004).

In this experiment, only the subordinate solution, which was determined in a pretest, was primed. The rationale to prime the subordinate solution only was as follows: It should be easier to boost the seldom used solution than the dominant solution, which per se has high activation when the gap-word is inspected. If genuine subliminal semantic activation exists, the probability of the primed solution should increase independent of strong masking conditions.

2.1 Methods

Material pretest. The original item set consisted of 108 German words with one letter missing, leaving at least two options to create a noun (e.g., T_NT, resulting in “tent” or “tint”). The pretest had two goals: First, words with more than two solutions were to be excluded from the target set. The second goal was to determine which solution was dominant over the other and which subordinate, or whether both solutions were equally frequent.

Thirty students took part in the pretest. Their mean age was 25.6 years; 19 were women, and all were native speakers of German. The task was to produce all possible solutions to each of the gap-words. Participants were told that a few possible solutions existed for each gap-word, and that they should start with the one that came to mind first, and to produce additional solutions, if possible. Solutions were restricted to German singular nouns; proper names were not valid.

The analysis left 90 gap-words as targets for the main experiment. Except for two word pairs, one solution was clearly dominant over the other (i.e. produced first or solely).

Participants. Eight students (two male) from the University of Braunschweig, age 20-35 years, (mean: 24.3 years) were tested in one-hour sessions. All were native German speakers, and took part for course credit.

Stimuli. 90 gap-words were used, each with one letter missing. On average, the stimuli were five letters long (including the gap). Each gap-word had two solutions (nouns of German in all cases), with one solution clearly dominant over the other. Two prime words were constructed for the non-dominant solution, of each one semantically related and one similar in form to the solution word.

Semantic primes. Semantic primes were constructed according to the following criteria: On average, they were five letters long, did not resemble the subordinate solutions in form, and were dissimilar to the dominant solution, both semantically and in from. All primes were semantically related to the subordinate solution (see table 2.1 for example stimuli, the whole word-material is given in the Appendix). 12.2 per cent of the primes were associates as well, 11.1 were synonyms, and in 17.8 per cent prime and target could be integrated into a compound-noun. The majority of primes (87.8 per cent) were thus semantically non-associated relatives. Bueno and Frenck-Mestre (2002) have shown that for masked primes semantic priming starts earlier than associative priming, therefore this relation seemed advantageous. Furthermore, in her meta-analytic review Lucas (2000) has shown that semantic priming can occur without association.

Form primes. The form-related primes resembled the target solution orthographically and phonologically. They were constructed to be similar to the primed solution (i.e. the subordinate solution) and dissimilar to the non-primed alternative solution. To specify form overlap, it was counted for each prime-target pair, how many letters of the target were part of the prime word also. A proportion index for each pair resulted. (For example: the form-prime ‘Krach’ contains three of four letters of the target word ‘Bach’, resulting in a proportion index of 75 percent). Overlap varied between 29 and 100 percent (when the target could be constructed out of the form prime) and was 72 percent in mean.

Efforts were made to equate the word length of semantic and form primes of each target word. On average, semantic and form primes were 5.32 and 5.16 letters long, respectively, and did not differ reliably [t(89)=.78; p=.439]. Neutral primes consisted of a string of four to eight question marks, matched in length to the longer of the two prime-words.

Table 2.1: Example stimuli of Experiment 1. The primed subordinate solution is presented with its respective primes (semantic/form). Translations are given in parentheses.

target	**subordinate solution**	**semantic prime**	**form-prime**	**neutral prime**
B_ch	Bach (creek)	Quelle (source)	Krach (noise)	??????
_agel	Hagel (hail)	Sturm (storm)	hager (lean)	??????

Design. The 90 gap-words were presented in random order in one block. Each participant completed all 90 target words within each block. This was replicated four times in the course of the experiment. The experiment consisted of four blocks, thus targets were repeated three times in the course of the experiment. Prime condition (semantic, form, neutral) was assigned randomly to each target in a block. Thus approximately on one third of the trials the non-dominant alternative was primed by a semantic prime, in another third by a form prime, and in the final third by a neutral prime. Therefore, primes were presented at least two times and at most four times in the course of the experiment.

Trial events. Stimuli were presented in black on white on an 85 Hz Iiyama Vision Master 407 monitor. Presentation durations were controlled by Presentation (Neurobehavioral Systems, Albany, CA), running on a personal computer.

On each trial a fixation cross was presented for 1600 ms, followed immediately by the first mask, the prime, the second mask and the target all centered at the same position on the monitor. Letters were approximately 0.95 cm high in mean, with a height of 0.8 cm for lower-case characters and 1.1 cm for capitals and those letters with ascenders or descenders, viewed from a distance of approximately 68 cm. All letters were presented in font type ‘Arial’, with font size 24, with a 640x480 pixels resolution, and a refreshing rate of 85 hz.

Prime duration was set at 23.5 ms. A sandwich mask procedure was used, with pre- and post-masks presented both for 117 ms. Masks consisted of three rows of randomly arranged, varying letters. The target appeared immediately after the second mask. Thus, prime-target stimulus asynchrony (SOA) was 140.5 ms. Targets remained visible until a response was provided. Temporal order of events and presentation durations is shown in figure 2.1.

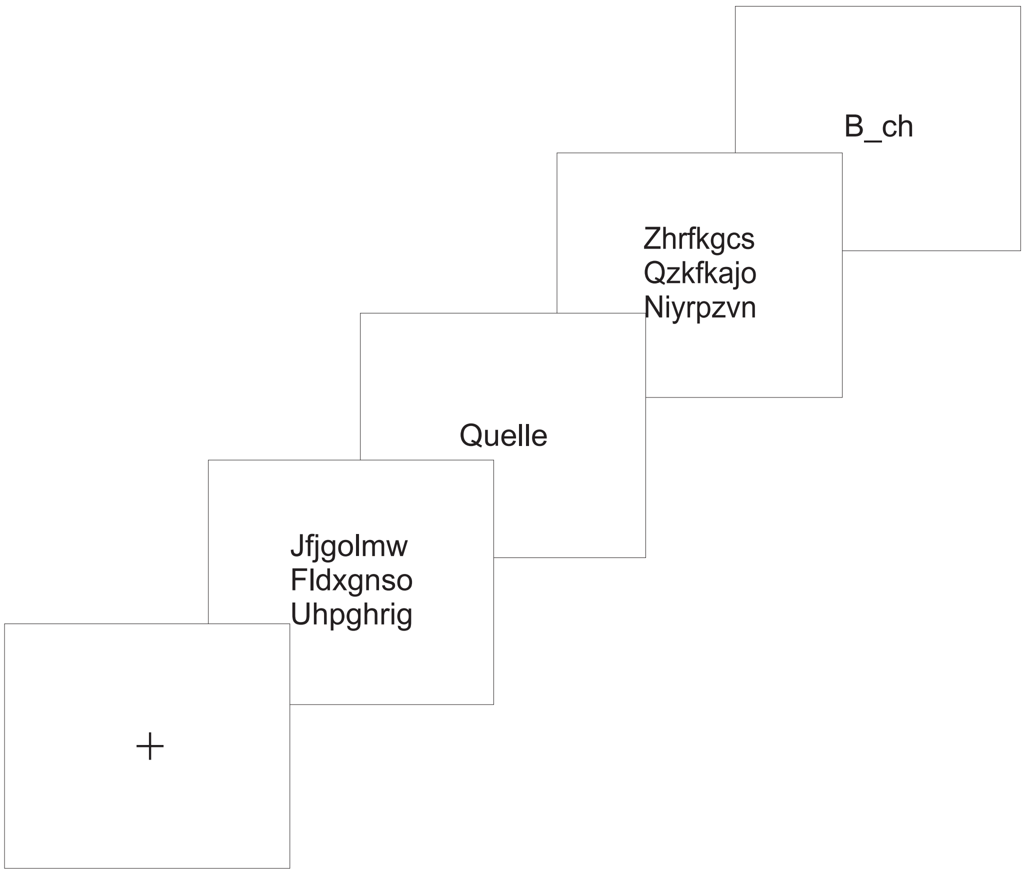

Figure 2.1: Order of trial-events in Experiment 1.

Task. The task was word-completion: Participants had to fill in the gap of the target stimuli, such that a legal German singular noun resulted.

Procedure. Trials started with a fixation cross shown for 1600 ms, followed immediately by the first mask, the prime, the second mask, and the target, all centered at the same position on the monitor. Responses were given on a standard keyboard. Participants were to speak out aloud the solution that came to mind, then to enter the letter on the keyboard which completed the gap-word without speed stress. After entering the completing letter, the trial finished; typos could not be corrected. Verbal responses were not recorded.

Instruction. Participants were instructed to complete each gap-word as fast and accurate as possible with the first solution that came to mind. They were informed that more than one solution for each gap-word existed, but that they should decide spontaneously, not strategically. After ten practise trials, the main experiment started. Participants were not informed about the existence of primes.

Data analysis. Targets were classified according to the solution given. Relative frequencies were computed from the number of processed trials for each condition. Arc-sine transformed frequencies were subjected to a repeated-measure ANOVA, with Prime-Type (semantic, formal, neutral) and, to control for repetition effects, Block (1-4) as independent variables. Additionally, an analysis of just the first block is reported. Here and in the following experiments, Huyn-Feldt corrected p-values are reported, which correct for potential non-normality in the residuals. For readability, F-values are reported with uncorrected degrees of freedom.

2.2 Results

Relative frequencies. Primes had an influence on word generation. The rate of completing the word with the subordinate solution increased, from neutral (0.21) to semantic (0.36) to form-related primes (0.43). This difference in means was highly significant [$F(2,12)=52.1$; $p<.0001$]; both contrasts between semantic and form primes [$F(1,6)=7.71$; $p<.05$] and between semantic and neutral primes [$F(1,6)=46.19$; $p<.0001$] were statistically reliable.

Note that all effects already existed in the first block (see figure 2.2). In fact, there was no reliable main effect of Block [$F(3,18)=0.86$; $p=.465$], nor an interaction Block x Prime-Type [$F(6,36)=0.53$; $p=.758$]. An ANOVA on the frequencies of just the first block confirmed this finding: The difference in means was highly significant [$F(2,12)=20.15$; $p<.0001$]; both contrasts between semantic and form primes [$F(1,6)=10.84$; $p<.02$] and between semantic and neutral primes [$F(1,6)=7.83$; $p<.04$] were statistically reliable at the first target presentation. This confirms that priming was stable and unchanging across the four blocks. The effect was reliable even at subject level, which is shown in figure 2.3.

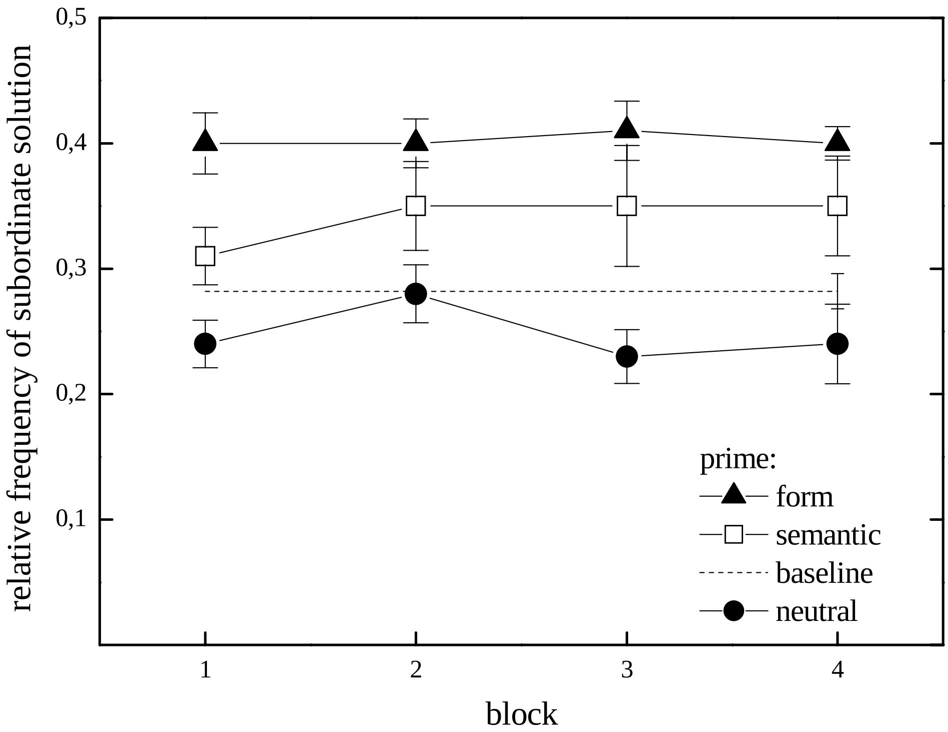

Figure 2.2: Mean relative frequencies of the subordinate solution as a function of prime condition (semantic, orthographic or neutral) and repetition. The dashed line presents the spontaneous frequencies of the subordinate solution in the pretest. Compared to both the pretest-baseline and the neutral prime condition, the primes led to higher frequencies of the subordinate solution.

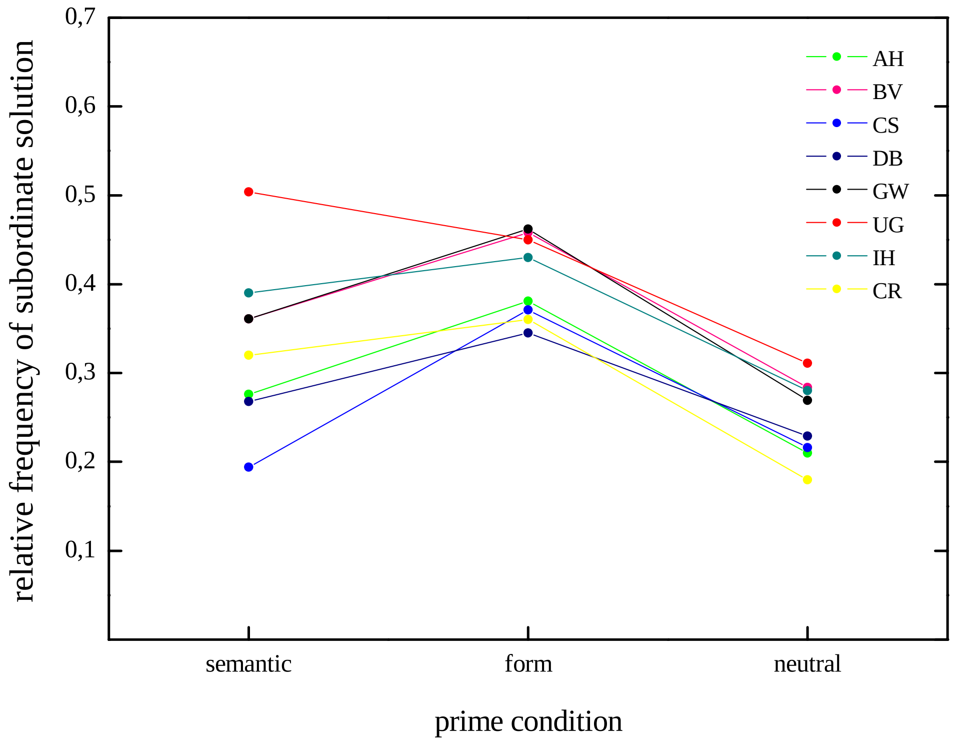

Figure 2.3: Relative frequencies of the subordinate solution as a function of prime condition and participant. Different colours present the different subjects participating in this experiment.

Response times. Responses were rather slow, with mean 1409 ms and standard deviation 895 ms. Because of unsystematic differences due to typing expertise of participants, response times were not further analyzed.

Prime visibility. After the experiment participants were interviewed and questioned whether they had noticed the prime words. Seven reported not to have seen any prime words, whereas one participant stated that he saw some primes from time to time, but was not able to read them.

2.3 Discussion

Substantial priming effects were observed, effects being strongest after form-related primes. The likelihood of coming up with the non-dominant completion of two possible response alternatives was substantially increased by the masked primes. The purpose of Experiment 1 was to demonstrate the existence of such priming effects in a word-completion task with two competing solutions. Importantly, the effect was apparent from the first presentation on and thus cannot have been due to repetition of prime-target pairs. Response priming cannot have caused the effect, as the response options changed from trial to trial. Priming of such a complex action as fragment completion demonstrates that the unconscious information processing goes beyond motor program preparation.

The observed semantic priming effects cannot be based on sublexical processes, because semantic and form-similarity were varied independently of each other. This indicates that the underlying mechanism operates at lexical-level, on semantic relations. However, the observed effects were stronger for form than for semantic primes. This leads to the question whether this difference is a general phenomenon, possibly due to a fast acting and early represented process in form-priming (operating on earlier stages), and a more complex mechanism in semantic-priming (operating on later stages), or whether it is due to the time frame chosen in the experiment. The SOA was set constantly at 140 ms. A variation of SOA could clear up this issue.

The chosen masking procedure seemed to produce strong masking. Other authors (e.g. Kiefer, 2002) have observed and produced evidence for strong masking under similar conditions (pre-mask of 100 ms, prime of 33.5 ms, and post-mask of 33.5 ms duration). Questioning the participants confirmed the observation that masking was efficient, but objective control over the visibility of primes was evidently lacking. An objective measure of prime discriminability was the main purpose of the following experiments.

3. Experiment 2a and 2b: Priming competing solutions

The results of the first experiment showed semantic and form priming of the subordinate solution. In Experiment 2a, priming was further investigated. Apart from replicating the observed effects, the impact of SOA on priming was determined. An obvious weakness of Experiment 1 was the lacking control of the masking procedure: was it efficient to produce conditions suitable studying unconscious prime processing? To answer this, a prime recognition task was added.

In Experiment 1 neutral primes were used, and although the probability of the subordinate solution after a neutral prime was comparable to its probability in the pretest, this condition is open to criticism. The neutral prime consisted of a string of question marks, and therefore was the only non-linguistic and massively repeated stimulus in the experiment. Hence, it might have been more visible than the other primes (see Kunde, Kiesel, & Hoffmann, (2003), for a similar finding). Although it is standard practise to chose a “neutral” condition as baseline, the term *neutral* remains a problem (Jonides & Mack, 1984). Differences to the neutral condition could as well result from facilitated target processing on primed trials, as from inhibited processing on neutral trials (Jacobs, Grainger, & Ferrand, 1995). Therefore priming was gauged differently here: In the present Experiments 2a and 2b, both solutions, the subordinate and dominant, could be primed in the course of the experiment. The assumption is that each solution becomes more probable when preceded by its related prime than when preceded by the prime of the concurring solution.

3.1. Experiment 2a

3.1.1 Methods

Participants. Eight students (eight female) from the University of Braunschweig, age 19-33 years, (mean: 22.4 years) were tested in two one-hour sessions. All were native German speakers, and took part for course credit. None of them had participated in Experiment 1.

Stimuli, word material. The 90 gap-words were the same as in Experiment 1. In addition to the primes for the subordinate solution, two new primes were constructed for each dominant solution, a semantic and a form prime. The primes for the dominant solution were five letters long in mean, did not resemble the subordinate solution in form, and were not semantically similar to it either. The new semantic primes were all semantically related to the dominant solution (see table 3.1 for example stimuli, and Appendix 1 for the whole set of words). 13 percent of the primes were associates as well, 9 percent were synonyms, and in 9 percent prime and target could be integrated into a compound-noun.

Table 3.1: Two example stimuli of Experiment 2a and 2b. Each solution (dominant / subordinate) is presented with the according primes (semantic / form). English translations are given in brackets.

target	**dominant solution**	**semantic prime**	**form-prime**	**subordinate solution**	**semantic prime**	**form-prime**
B_ch	Buch (book)	Seite (page)	Tuch (sheet)	Bach (creek)	Quelle (source)	Krach (noise)
_agel	Nagel (nail)	Hammer (hammer)	Nadel (needle)	Hagel (hail)	Sturm (storm)	hager (lean)

Design and task. The design was the same as in Experiment 1, except for the following: Four prime conditions were referred to the targets. Due to programming error, a fixed prime-target combination was assigned throughout the experiment. In Experiment 1, the prime for each target was assigned randomly in each block (e.g. the target ‘B_ch’ was presented with the neutral prime ‘???????’ in the first block, with the subordinate-form prime ‘Krach’ in the second block, with the neutral prime in block three, and with the subordinate-semantic prime ‘Quelle’ in the last block). In the present Experiments 2a and 2b, one of the four possible primes was assigned to each target for the complete experiment (e.g. the target ‘B_ch’ was presented with the semantic prime for the dominant solution ‘Seite’ in all four blocks). Thus in this and the following experiment 2b, the subsequent blocks represent full prime-target pair repetitions. This mistake offered the possibility to control the effects of fixed prime-target assignments. In Experiment 1 and again in Experiments 3-5b, the prime-target assignment was random, thus the results can be compared.

SOA was varied between 140 and 240 ms. The target was randomly presented either immediately after the second mask (SOA=140.5 ms), or after a blank screen for 100 ms which was presented after the second mask (SOA=240.5 ms). Prime and mask duration remained at 23.5 and 117 ms respectively. The task in the first session was fragment completion, as in the first experiment.

Recognition task. Prime awareness was measured in a second session. After the interview, participants were informed about the occurrence and the structure of the primes, and were instructed to focus attention on them this time. The same stimuli as in session one were presented (see figure 3.1). An additional frame was presented at the end of each trial, which showed both solutions of the gap-word. The two possible letters were presented above and below the gap with positions counterbalanced across participants and targets. For each participant, the dominant solution was presented above the gap for half of the targets and below for the other. For each target, the dominant solution was presented above for half of the participants, and below for the other. This last frame was presented to insure that participants knew both solutions. Participants were instructed to decide between the two alternatives and to enter the solution which they thought had been primed on the keyboard. Thus the direct task was to decide which solution had been primed on the current trial.

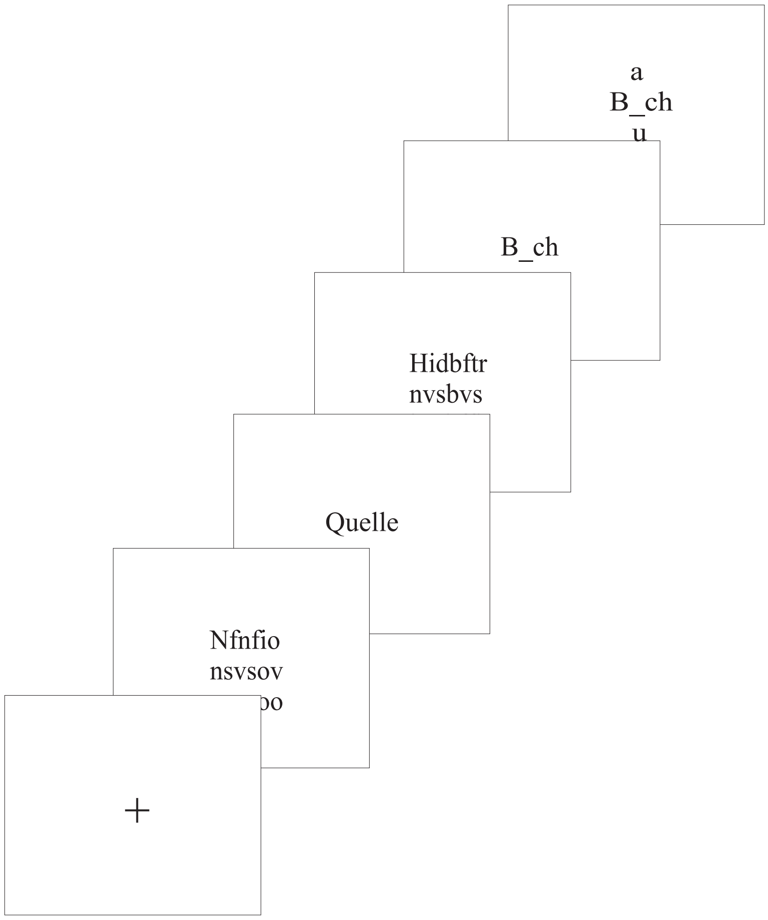

Figure 3.1: Trial structure in the recognition task used in Experiment 2a and 2b.

A process-dissociation procedure (Jacoby, 1991; Debner & Jacoby, 1994; Stern, McNaughts-Davis, & Barker, 2003) was introduced in the prime-recognition task. Process-dissociation is used basically in stem-completions (e.g. Debner & Jacoby, 1994). In this task, words are presented to the participants which they have to process actively (e.g. lexical decisions) or passively (e.g. priming tasks). Subsequently, participants are confronted with word-stems, and instructed to complete these stems with any word, except those they have seen before (exclusion instruction) or especially with one of the words they have seen before (inclusion instruction). Jacoby (1991) assumed that conscious and unconscious perception act in concert and that, under the assumption of independent effects of conscious and unconscious perception, the probability of conscious perception can be estimated by performance under inclusion minus exclusion. This account offers the advantage of being able to separate between conscious and unconscious perception, without the burden to prove that stimuli in one condition (e.g. masked trials) fully remain outside of awareness (Debner & Jacoby, 1994).

Introducing inclusion-exclusion instructions into the present prime-recognition task offered the advantage of being able to separate between participants ability to execute the instruction from their skill to discriminate the prime words. Furthermore, since the solutions were not equally probable, it seemed fruitful to force the participants to use different strategies. In each block of 90 trials, participants should either enter the solution which they thought was primed (inclusion (I) condition) or the solution which they thought was not primed (exclusion (E) condition). The order of I and E blocks was counterbalanced between participants (IEIE vs. EIEI). An instruction with the beginning of each block defined which task had to be performed.

Procedure. The priming task was identical to Experiment 1. Trials in the recognition task were identical to the priming task, except that gap-words were presented for 1000 ms and then followed by the solutions which remained there until response occurred. A trial was finished by the reaction of the participant.

Data analysis. Arc-sine transformed relative frequencies were subjected to a repeated measures 2x2x4x2 ANOVA with Prime-Direction (dominant, subordinate), Prime-Type (semantic, form), Block (1-4), and SOA (140/240) as factors. Recognition performance was analyzed by signal detection methods, based on hits and false alarms per subject and condition.

The reported relative frequencies are based on the actually processed number of trials (n). Therefore the percents of subordinate and dominant solutions always sum up to 100 percent. In the following, the frequencies of the subordinate solution are presented in the figures, except when explicitly mentioned. The frequency of the dominant solution is just that of one minus the frequency of the subordinate.

3.1.2 Results

Solution frequencies. Masked primes had an impact on which solution was given. When preceded by a semantic prime, the subordinate solution was given in 37 % of trials. Conversely, when the prime of the dominant solution was presented, this probability decreased to 32 %. Numerically, form primes had a stronger impact on response selection, with 37 % in the congruent (prime related to the subordinate solution) and 22 % in the incongruent (prime related to the dominant solution) condition.

The effect of Prime-Direction was reliable [$F(3,7)=26.35$; $p<.005$]. The interaction of Prime-Type and Prime-Direction however missed statistical significance [$F(1,7)=4.30$; $p=.077$]. Figure 3.2 shows the overall priming effects.

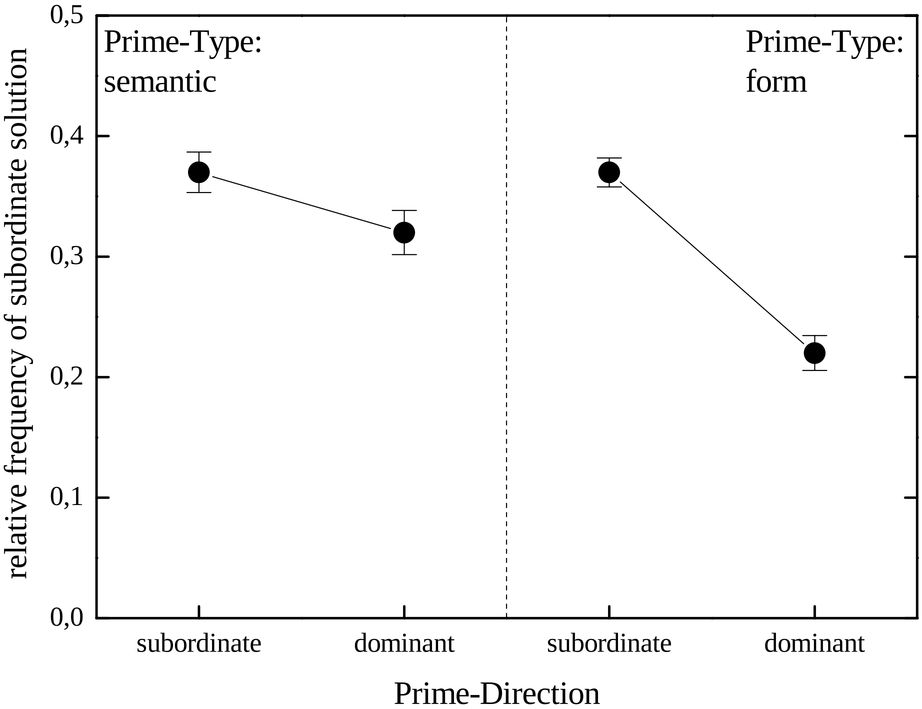

Figure 3.2: Relative frequencies of the subordinate solution as a function of Prime-Direction and Prime-Type.

The interaction of Block and Prime-Direction turned out non-significant [$F(3,21)=.07$; $p=.95$]. The observed priming effect was thus stable across blocks and, did not increase with repetition. The interaction between SOA and Prime-Direction was not reliable [F(1,7)=.05; p=.836] too, but the interaction of block with SOA [F(3,21)=3.61; p<.05] and the triple interaction of Block, Prime-Type and SOA turned out reliable [F(1,7)=18.23; p<.005]. This is illustrated in Figure 3.3, where the response frequencies are shown as a function of Prime-Type, Block and SOA. Semantic priming was observed on long SOA trials only, where it even decreased with repetition. All other interactions turned out non-significant.

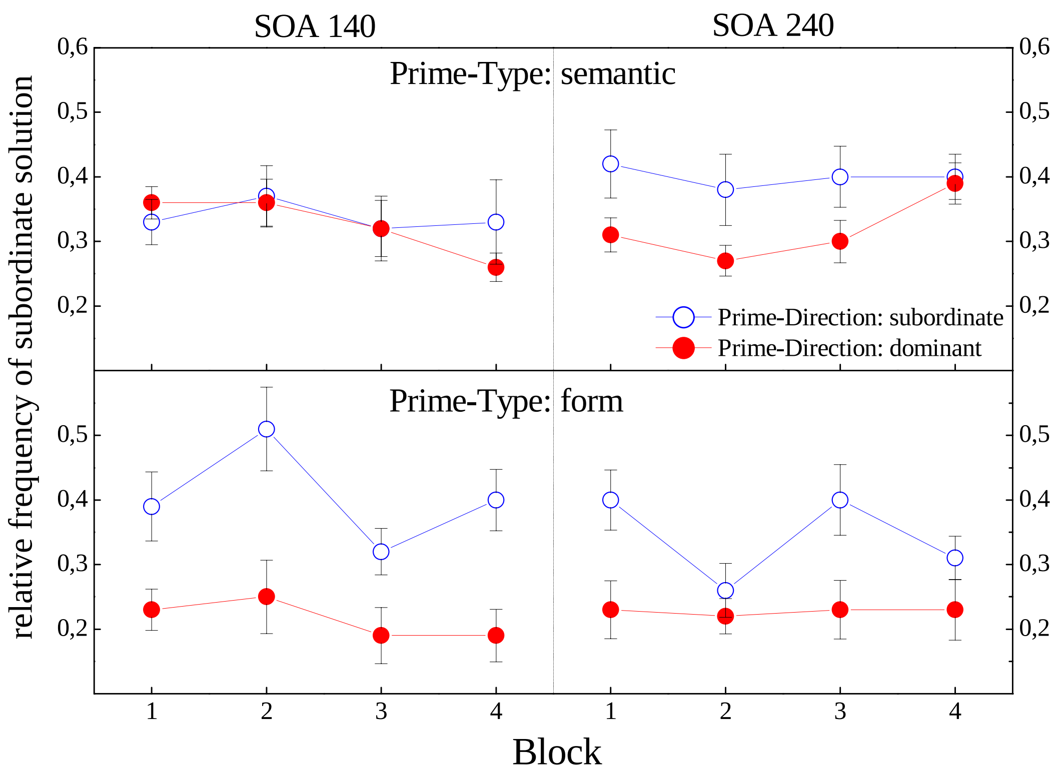

Figure 3.3: Relative frequencies of the subordinate solution, as a function of Prime-Direction, Prime-Type, SOA, and Block. The upper half of the graph shows semantic, the lower half form priming conditions. Inspection of the data shows no semantic priming in the short SOA condition, but only on long-SOA trials. Form-priming is apparent at both SOA durations.

Prime recognition. The prime recognition task revealed that participants could in fact make conscious use of the prime. In the inclusion condition, performance was correct in 53.2 percent of trials, in the exclusion blocks, decisions were right in 58.4 percent. Figure 3.4 shows that correct decisions were more frequent in the dominant-prime condition (66 vs. 45 percent).

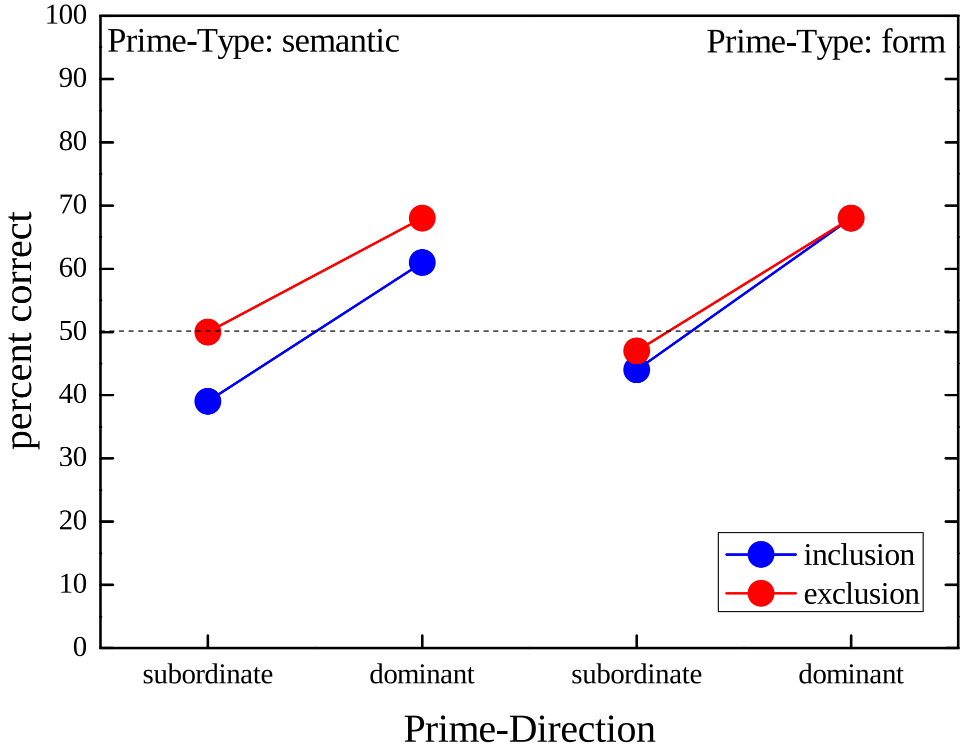

Figure 3.4: The percentages of correct prime recognition are given as a function of instruction (inclusion, exclusion), Prime-Direction (subordinate, dominant), and Prime-Type (semantic, form).

Higher performance with dominant primes seems due to a response bias: In 62 percent of trials in inclusion blocks, participants chose the dominant solution, whereas in exclusion blocks, participants chose the subordinate solution in 60 percent. This demonstrates a response bias in favour of the dominant solution of about 60:40.

To eliminate the influences of an asymmetrical response distribution between the solutions, the data were sorted in hits and false alarms. Hits were defined as those trials where the actually present prime and the chosen solution were related, no matter what task instruction was. For clarity, this scheme is presented in Table 3.2.

Table 3.2: Classification of hits and false alarms.

	response	
prime stimulus	“Bach”	“Buch”
prime for “Bach”	**hits**	misses
prime for “Buch”	**false alarms**	correct rejections

The differences of the z-transformed and false alarms (*d’*) are presented in Table 3.3 where the *d’* values are reported per subject and condition. For the exclusion blocks, *d’* was multiplied with factor -1.

Table 3.3: Mean *d’* values in the recognition task per participant and SOA.

participant	***d’***	
	SOA=140	SOA=240
1	.29	.85
2	.57	.19
3	.07	.58
4	.57	.67
5	.23	.40
6	-.01	.28
7	.40	.20
8	.23	.04

Mean *d’* significantly exceeded zero, which corresponds to above-chance performance [$t(63)=6.522$; $p < .0001$]. The ANOVA with Block and SOA as factors showed a main effect of Block [$F(3,21)=3.21$; $p<.05$]. SOA had no reliable impact on recognition performance [$F(1,7)=.783$; $p=.406$], see figure 3.5. Overall *d’* was .19 under inclusion and .48 under exclusion conditions, the difference in performance was significant [F(1,7)=7.45; p<.03]. Prime-Direction had an impact on recognition performance [F(1,7)=16.25; p<.002], with higher performance for dominant (d'=.93) than for subordinate primes (d'= -.26).

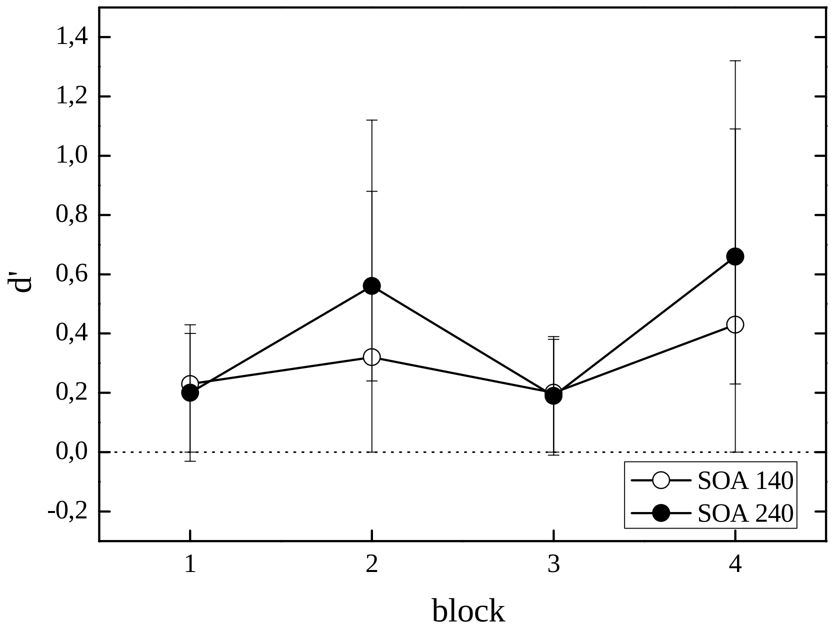

Figure 3.5: Recognition performance (*d'*) as a function of block and SOA. Error bars represent standard errors of means. Inspection of the graph reveals no clear dependency on SOA or on block, but recognition performance is greater than chance level overall.

The data are presented in Figure 3.6 in the same format as in the priming-task, as a function of prime and instruction. The figure shows that the subordinate solution becomes more probable when it is preceded by a related prime. This increase is stronger under exclusion than under inclusion instruction, where the frequency of subordinate solutions is overall higher.

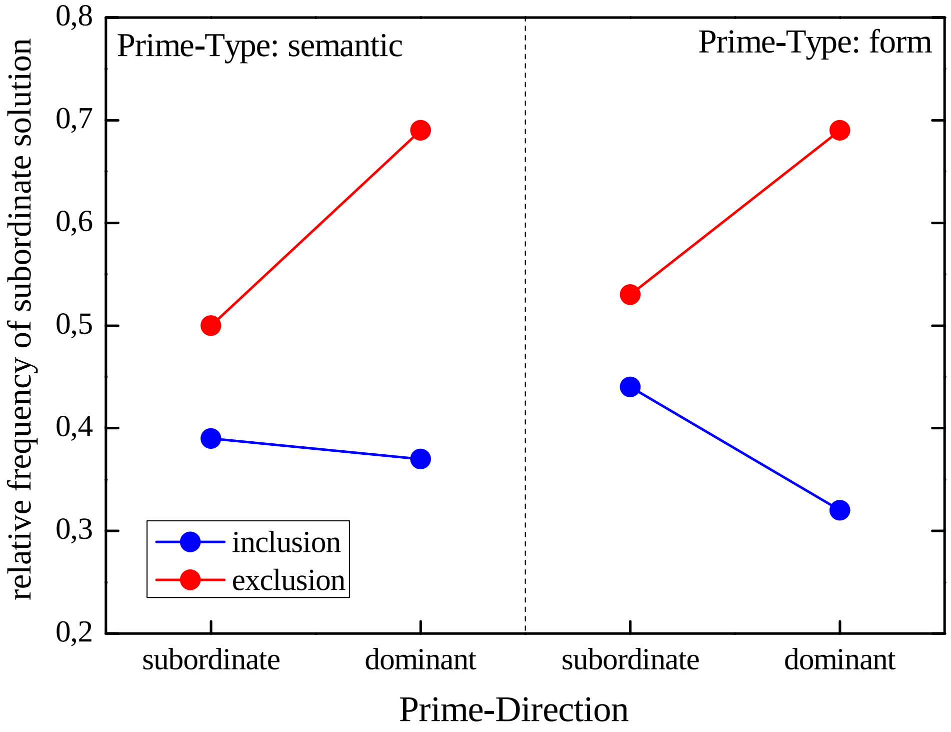

Figure 3.6: Relative frequency of the subordinate solution as a function of Prime-Direction (subordinate, dominant), Prime-Type (semantic, form) and instruction (inclusion, exclusion) in the recognition task.

3.1.3 Discussion

Experiment 2 showed both form and semantic priming, with stronger semantic priming in the long SOA condition, and almost no semantic priming on short-SOA trials; a finding not present in Experiment 1. Different from Experiment 1, the present experiment used primes corresponding to either the subordinate or the dominant solution, rather than neutral primes. If masked primes had no influence on fragment completion, a particular solution should be equally frequent when preceded by its related prime or by the prime related to the concurring solution. However, clear differences in the frequency of a solution depending on prime-direction were observed. The present experiment showed that priming did not increase with blocks, rather a decrease was observed. The effect was fully expressed at the first prime-target presentation.

The recognition task showed that participants, although stuck to a response bias for the dominant solution, were able to use the prime information. Recognition performance was above chance. One interpretation of this finding is that the observed priming effect was in fact due to small residuals of conscious prime processing. This is in contrast, however, to the subjective report of participants and to the findings of other authors who reported chance performance in discrimination under even weaker masking conditions (e.g. Kiefer, 2002).

Alternatively, the automatic activation of the prime could have influenced participant's responses in the prime recognition task as well as in the priming task. Participants had to select between two competing solutions in the recognition task, they had to decide which of the two was primed on the current trial. Even if primes remained outside of conscious perception, the forced-choice between both solutions could have been influenced by the prime, meaning that the recognition task was not capable to separate the direct from the indirect effects of the primes. As the response pattern in the recognition task strongly resembles that in the priming task, this interpretation cannot be ruled out with the present data. To clarify this issue, the experiments presented in the following manipulated the amount of masking (in the following Experiment 2b) and introduced alternative recognition tasks (Experiment 4, 5a and 5b) designed to separate between automatic prime activation and conscious prime recognition.

3.2 Experiment 2b

Experiment 2a showed priming on word generation. In contrast to Experiment 1, which included the 140 ms SOA-condition only, semantic priming was observed only on long-SOA trials in Experiment 2a. The recognition data showed that the decision between the two given solutions was influenced by the prime too. However, two alternative interpretations are possible: First, the observed priming effects could be based on residuals of conscious processing, a hypothesis in line with arguments of Holender and Duscherer (2004). Second, the recognition task could reflect automatic activation of the prime. Because the task was to decide between two solutions, the prime's activation for one of them could have produced the results as well.

Experiment 2b is a replication of Experiment 2a with one small variation: In order to clarify whether prime visibility or prime impact had produced above chance recognition, the amount of masking was varied. If the previous results were due to prime activation rather than prime-visibility, and solution priming was unaffected by mask-length, recognition performance should be unaffected by the amount of masking.

3.2.1 Methods

Participants. Five new students (all female) from the University of Braunschweig, age 19-30 years, (mean: 23.4 years) were tested in two one-hour sessions. All were native German speakers, and took part for course credit.

Stimuli, design, task and procedure were identical except for the following. On long (240 ms) SOA trials, the post-mask was presented either for 110 ms or 210 ms. The following combinations resulted: SOA 140 ms / post-mask 110 ms, SOA 240 ms / post-mask 110 ms, and SOA 240 ms / post-mask 210 ms.

Data analysis. Because mask duration was varied on long-SOA trials only, two separate ANOVAs were performed upon the arc-sine transformed relative frequencies of the subordinate solution. First, the effects of Prime-Direction (dominant, subordinate), Prime-Type (semantic, form), Block (1-4) and SOA (140, 240) were investigated. In the second analysis, a combined factor of mask-duration and SOA (short SOA / short mask, long SOA / short mask, long SOA / long mask) was entered into the ANOVA, which controlled Prime-Direction and Prime-Type similarly.

Recognition performance was analyzed by signal detection methods, based on hits and false alarms per subject and condition. Apart from an analysis of *d’*, an ANOVA on the relative frequencies of the subordinate solution was performed to control for prime and instruction effects.

3.2.2 Results

Solution frequencies. Masked semantic primes increased the frequency of subordinate solutions from .28 to .39. Form primes affected the probability of the subordinate response as well, with a rise from .21 to .40. The overall effect of Prime-Direction was significant [$F(1,4)=8.96$; $p<.05$]. The interaction of Prime-Direction with Prime-Type was significant as well [$F(1,4)=8.73$; $p<.05$], as priming was more stable in the form condition (see figure 3.7). Block and SOA showed no reliable influence on response choice, nor did any of the interactions including these factors.

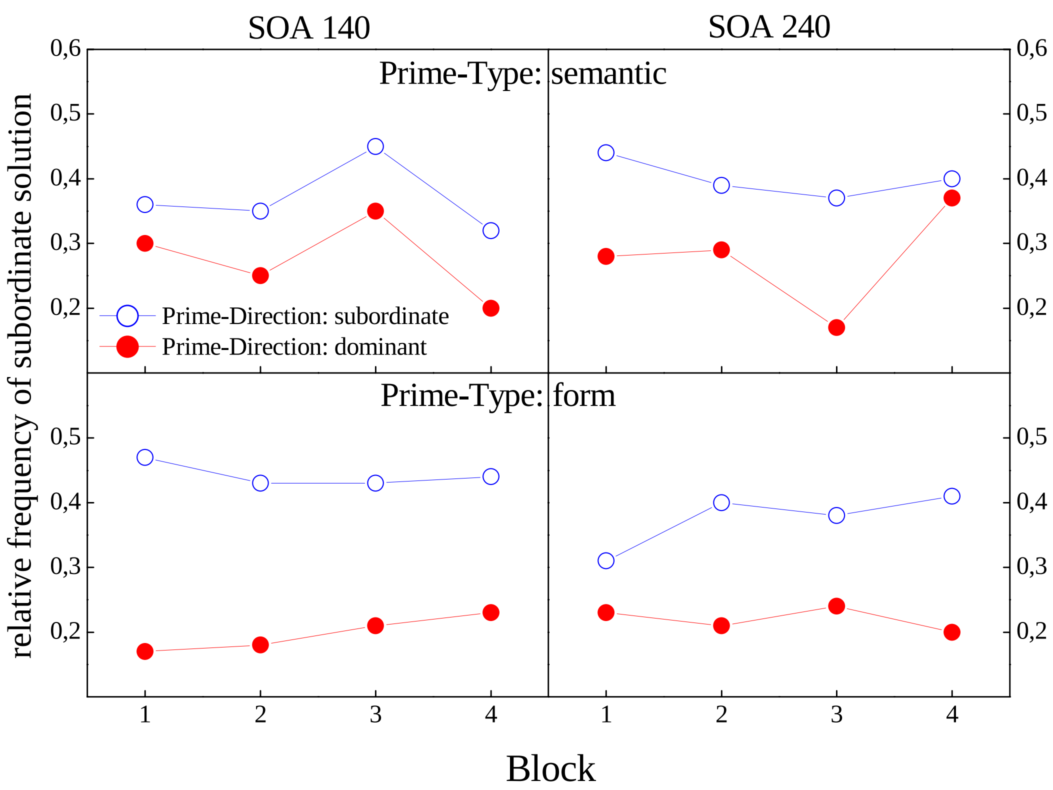

Figure 3.7: Relative frequencies of the subordinate solution as a function of Prime-Direction, Prime-Type, SOA, and Block. The upper half of the graph shows semantic, the lower half form priming conditions.

Figure 3.8 shows priming as a function of mask duration, displaying that priming was independent of mask duration. The second ANOVA controlled for the combined effect of SOA and mask duration on response selection. As block had no impact on solution frequency, data were aggregated across this factor. Prime-Direction was reliable [$F(1,4)=7.66$; $p<.05$], and did not interact with mask/SOA [$F(2,8)=.36$; $p=.710$]. The main effect of mask/SOA was not reliable either [$F(2,8)=2.01$; $p=.196$].

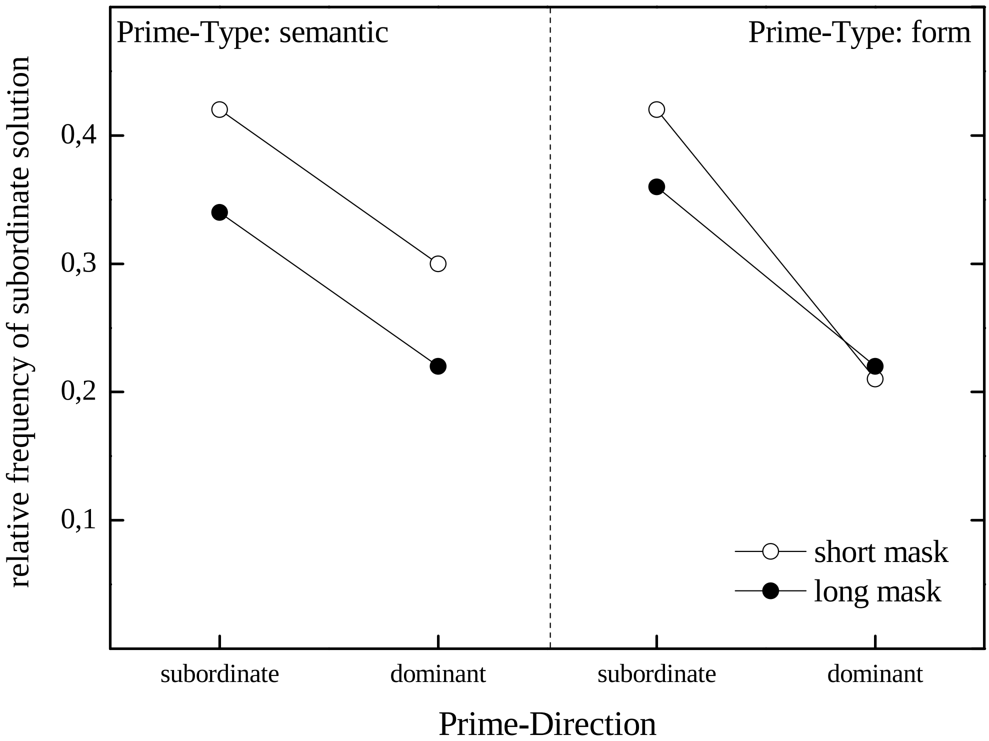

Figure 3.8: Relative frequency of the subordinate solution, as a function of Prime-Direction, Prime-Type and mask duration.

Prime recognition. Overall, participants were correct in 57 % of their judgements, which corresponds to an overall *d’* of .42. Due to great variability between participants (which ranged from -.23 to 1.47), this was not significantly different from zero [$t(4)=1.3$; $p=.26$]. Prolonging mask duration had no impact on performance with *d’*=.42 for short and *d’*=.41 for long masks.

Figure 3.9 presents the frequencies of the subordinate solution; again a clear dependency on prime condition is observable. Response bias for the dominant solution was .58 overall.

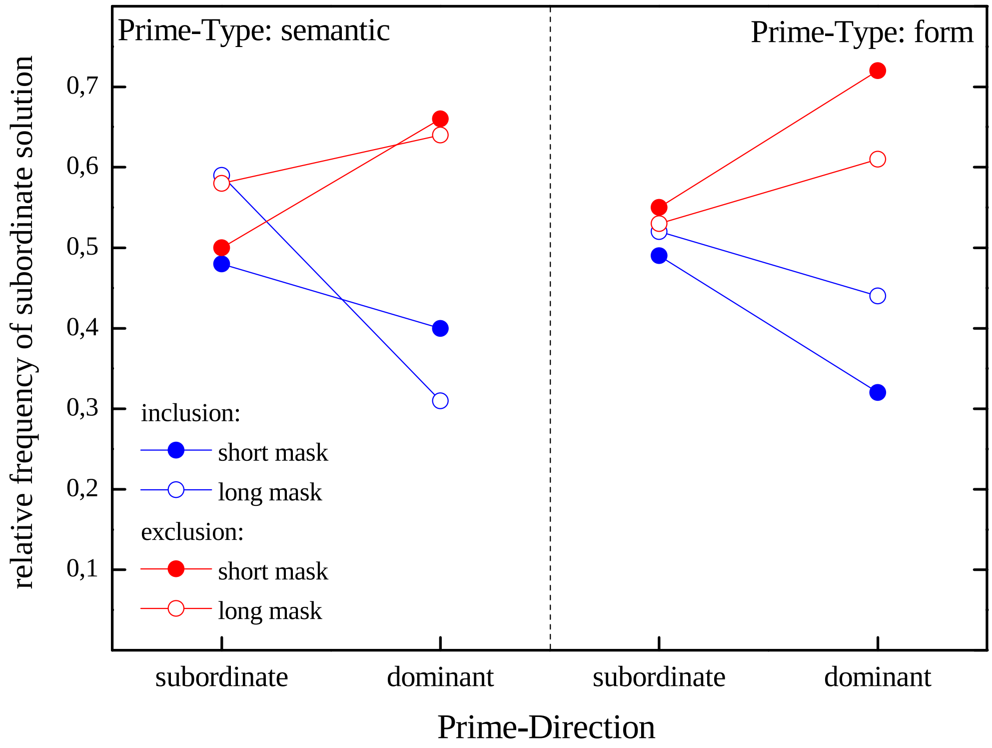

Figure 3.9: Prime recognition: Frequency of the subordinate solution as a function of Prime-Direction, Prime-Type, task (inclusion / exclusion) and mask duration.

Figure 3.9 shows an influence of mask duration for the form primes. The pattern of results is as expected: Better performance after shorter as compared to longer masks. However, this pattern is not seen in the semantic condition [$F(1,5)=.003$; $p=.957$].

Recognition performance was correlated with amount of priming. Figure 3.10 shows net priming in *d'* as a function of recognition performance. To make priming and recognition performance more comparable, priming was expressed over the effect-strength measure *d'*. The correlation of .25 was not reliably larger than zero ($p=.345$).

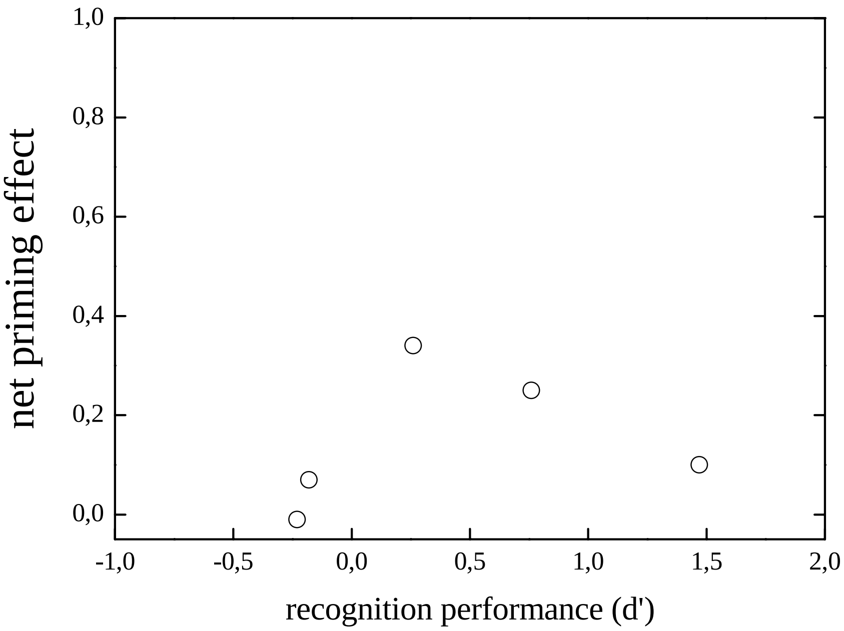

Figure 3.10: Net priming as a function of recognition performance.

3.2.3 Discussion

The priming effect on word-generation was reproducible, even within a small sample of participants. In contrast to Experiment 2a the results of Experiment 2b showed semantic priming effects at both SOA durations. Again, form-priming was stronger and more stable than semantic priming, which suggests a more reliable influence, less influenced by confounding variables. The observed priming effect was not influenced by mask duration, and did not change with SOA. The repeated presentation of fixed prime-target pairs did not lead to an enlargement of the effect; all effects were observed in the first block already.

The results of the recognition task replicate the findings of Experiment 2a. Primes did influence recognition decisions in the task. Again, this can be interpreted as showing that conscious processing is causal for priming, and that the observed priming effects are based on processing of fragments. Alternatively, the automatic effect of the prime might have produced both findings.

If prime visibility caused the effects in the word-generation and in the recognition task, priming effects should have been stronger in the short mask condition, but the observed priming effects were comparable after short and long masks, however, varying mask duration did not affect prime visibility. Only in the form-prime condition, a longer mask lowered recognition performance in both the in- and exclusion task. Yet, the observed independence of priming from mask-duration should be interpreted carefully, because only a small number of subjects were tested. The mask-duration variation might have been insufficient to produce different visibility degrees. The argument that priming was independent of masking can thus not be supported with the present data, because no clear masking differences existed. The present experiment could thus resolve this issue, but gives further evidence for the existence of both routes of activation.

The question remains, how the results have to be interpreted. Were the observed effects in the recognition task unconscious priming effects or based on remainders of conscious prime-processing? To clear up this issue, Chapters five and six will present an alternative recognition task, which reduces probable implicit effects in the prime recognition task.

4. Experiment 3: Effects of word material

The present experiment was designed to control for the effects of two variables which might have played a confounding role in the previous experiments: word-frequency and solution-dominance. Dominant and subordinate solution words were not equalized with regard to their word frequency, because only very few gap-words exist, which have two solutions equally frequent. This may have caused a confound between dominance and frequency of a solution word, with dominant solutions being more frequent than subordinate ones. Therefore it seemed necessary to examine whether high and low-frequency words elicit comparable priming effects. The expectation was that masked priming should be independent from word-frequency, as was also found for masked categorization priming (Bueno & Frenck-Mestre, 2002).

Solution dominance might also have interacted with priming. Although one of the two solutions always dominated the other one, the frequency with which the subordinate solution was given as the first solution in the pretest differed considerably between the gap-words. Some subordinate solutions were hardly ever chosen in the pretest; whereas others were given from 40 percent of participants as the first solution (see Appendix, Table 9.1). Therefore it seemed necessary to check whether priming was observed for all word-pairs, or whether it was observed only if solution dominance was low and both solutions were given similarly often (e.g. frequency of .60 for the dominant and of .40 for the subordinate solution in the pretest).

To control for the above mentioned differences between word-pairs, a target-wise analysis was performed. The aim of the experiment was thus to corroborate the so far found effects, and to analyze if priming was at all dependent on other variables as prime relation. Also, mask duration was varied orthogonally with SOA in this experiment, and prime-target assignment was random again, as in Experiment 1.

4.1 Methods

Participants. Nine new students (eight female) from University of Braunschweig, age 20-37 years, (mean: 23.0) were tested in two one-hour sessions. All were native German speakers, and took part for course credit. None had participated in one of the preceding experiments.

Stimuli, design, task and procedure were identical to Experiment 2a, except for the following. In addition to SOA, mask duration was varied (60 vs 120 ms). Prime-Direction and Type were randomly assigned to targets in each block, thus each block was a full replication of the complete design.

Data analysis. ANOVAs were performed on the arc-sine transformed relative frequencies of the subordinate solution, with Block (1-4), Prime-Direction (dominant, subordinate), Prime-Type (semantic, form), SOA (140, 240 ms) and Mask-Duration (60, 120 ms) as factors. In additional analyses, degree of dominance and frequency effects on priming were controlled. An item-analysis was performed, which controlled for effects of target material.

4.2 Results

Solution frequencies. The solution given was influenced by the prime. When preceded by a semantic prime related to the subordinate solution, the subordinate solution was given in 37 percent. When preceded by a semantic prime for the dominant solution, this frequency reduced to 28 percent. Thus a related prime increased the frequency of the subordinate solution, whereas a prime related to the dominant solution reduced its frequency. The same pattern of results was observed for form-primes: The frequency of subordinate solutions was 34 percent after related form primes, and 28 percent after form primes related to the competing dominant solution. Figure 4.1 presents these priming effects as a function of block.

These findings are corroborated by statistical analyses. Prime-Direction was statistically significant [$F(1,5)=14.39$; $p<.02$]. As Prime-Type did not interact reliably with Prime-Direction [$F(1,5)=3.68$; $p=.113$], priming was equally strong after semantic and form primes. The interactions of Prime-Direction with Block [F(3,15)=.98; p=.388] and with SOA [F(1,5)=.82; p=.407] turned out non-reliable either, thus priming did not vary with any of these variables. Shortening mask duration did not modulate frequency priming [F(1,5)=.003; p=.955]. None of the higher-order interactions turned out significant. Note that the reported degrees of freedom vary from their expected values, because four of the nine subjects were confronted with three of the four blocks only due to programming error. The analysis led to the same results nevertheless when computed on three blocks, using the first three blocks per participant only.

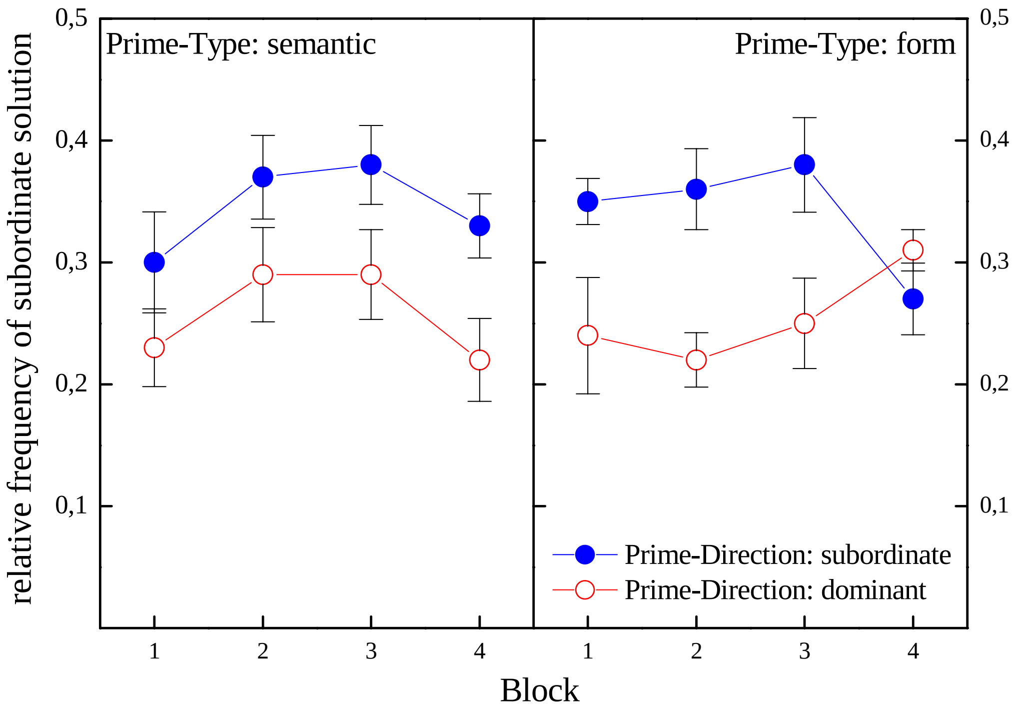

Figure 4.1: Relative frequencies of the subordinate solution as a function of Prime-Direction, Prime-Type, and Block.

Effects of word material: Single target analysis. First, the question was posed whether the observed effects were based on the activation of some solution-words only. Figure 4.2 presents the frequency of each subordinate solution when it was primed as compared to when the dominant solution was primed.

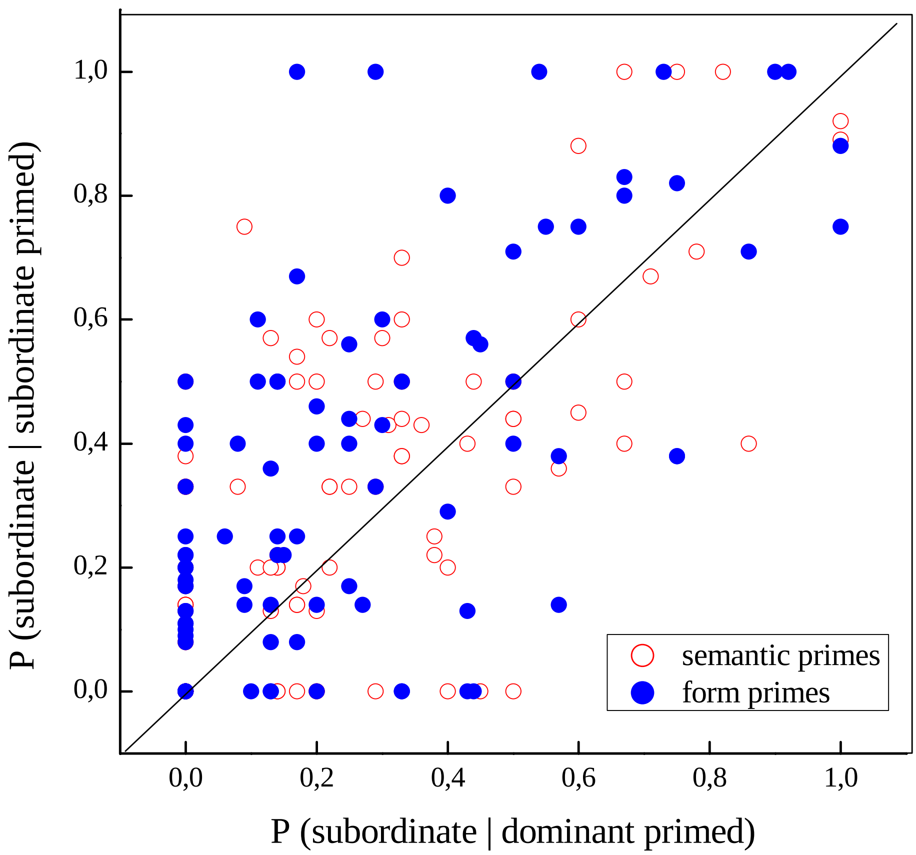

Figure 4.2: Frequencies of subordinate solutions when primed compared to when competitively primed. Each point presents one of the 90 words.

As shown in Figure 4.2, priming effects were observed for several gap-words, but obviously not for all of them. Whereas some subordinate solutions were never produced and some more frequently, they were overall more probable after their related primes. This was confirmed by an item-based ANOVA which used targets as variance source rather than participants. The results confirmed the previous findings: Prime-Direction had significant influence on solution frequency [$F(1,89)=18.99$; $p<.0001$], whereas the interaction with Prime-Type turned out non-reliable [$F(1,89)=1.25$; $p=.266$].

Effects of word material: Degree of solution dominance. To determine which factor controls whether solutions can be primed, dominance of solution as a factor was investigated. Although one solution was always dominant over the other in the target-set, some subordinate solutions were produced more often than others, thus were less subordinate than others. It is conceivable that only those solutions can be triggered by a prime which are more accessible anyway. Therefore, solutions were divided into three dominance-classes, based on spontaneous frequencies in the preliminary investigation (see Experiment 1 and Appendix). Subordinate solutions were entered the classes as follows: frequency in pretest of .00-.23 = class one, .24-.34 = class two, .35-.49 = class three. Each class consisted of 30 targets.

Degree of solution dominance had no systematic on priming, as shown in Figure 4.3. As expected, a main effect of dominance was observed, with less frequent given subordinate solutions in the most subordinate class, and increased frequencies to the third category, in which subordinate solutions were given in nearly half of the time [$F(2,16)=13.41$; $p<.0001$]. The observed priming effect was unaffected by this rise [Prime-Direction x Dominance: $F(2,16)=.04$; $p=.959$]. This was true for both semantic and form priming, as the triple interaction of Prime-Direction x Prime-Type x Dominance turned out non-reliable too [$F(2,16)=2.07$; $p=.160$]. Thus priming was observed for highly subordinate solutions as well as for solutions which were more frequent in spontaneous completion.

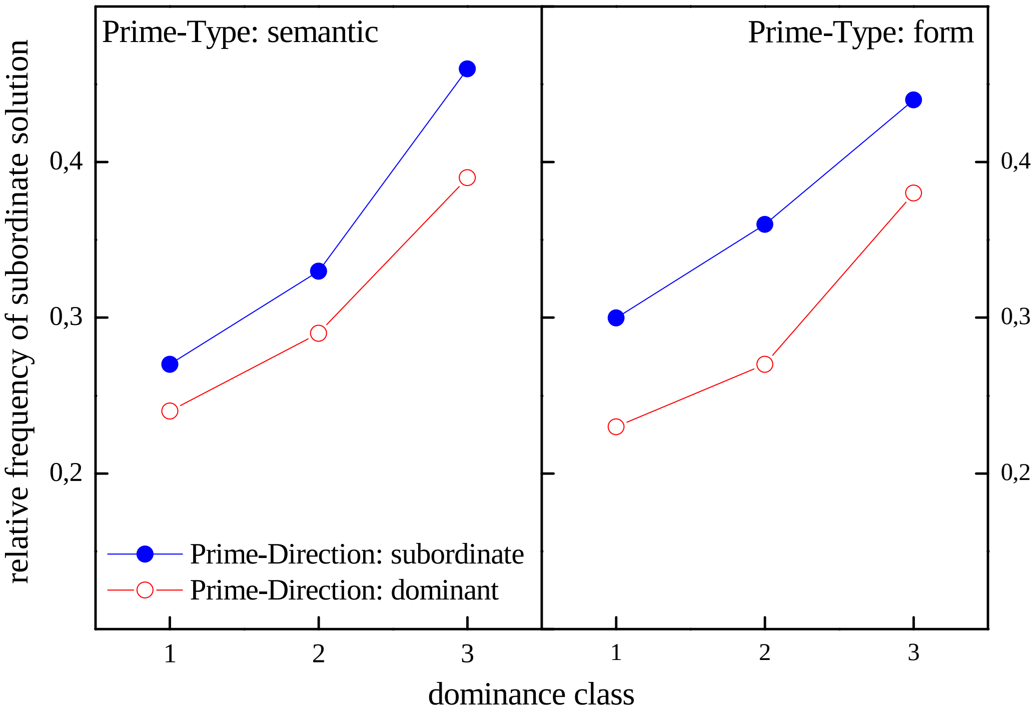

Figure 4.3: Relative frequencies of the subordinate solution as a function of Prime-Direction, Prime-Type and dominance class.

Word frequency effects. Apart from their differing availability, the solution-words differed in their overall word frequency in everyday-life language. For the majority of the targets (54 solutions), the subordinate solution was also the less frequent word. However, for the remaining 36 targets, the subordinate solution was at least as frequent as the dominant solution, indicating that completion is influenced but not fully determined by word-frequency. Frequency rates for each solution word were taken from the German Thesaurus Dictionary (University of Leipzig). Figure 4.4 presents the priming effect for solution-pairs for which the dominant solution was also the more frequent word, compared to pairs with the subordinate solution at least as frequent as the dominant solution.

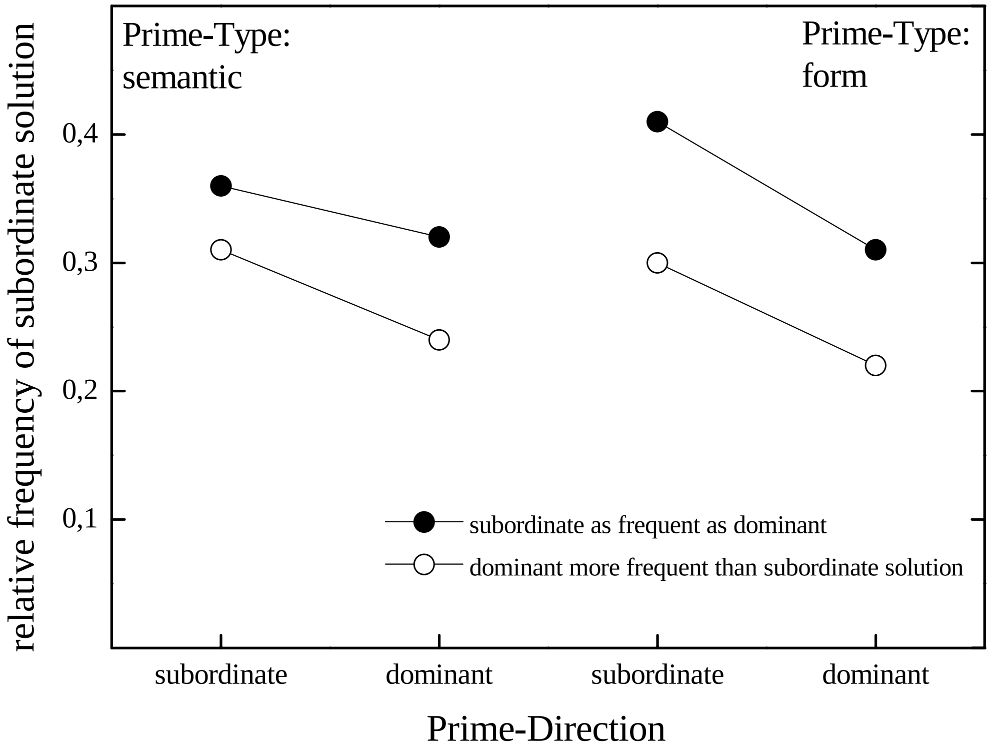

Figure 4.4: Relative frequency of the subordinate solution as a function of Prime-Direction, Prime-Type and the frequency of the subordinate solution in everyday language compared to the dominant solution. Priming is unaffected by solution-frequency.

As is obvious in Figure 4.4, subordinate solutions were produced more often when their word-frequency is at least as high as that of the dominant solution. Note that even high-frequency subordinate solutions were still produced in less than half of the time.

Solution-priming was independent of word-frequency (see Figure 4.4), which was corroborated by a statistical analysis with targets as variance source and solution-frequency as between group factor (precisely: between-word factor): Prime-Direction did not interact with solution-frequency [$F(1,88)=.40$; $p=.529$].

Prime recognition task. Participants' decision which solution was primed (inclusion) or not primed (exclusion) on the current trial was influenced by prime condition. Performance was above chance with 54.4 percent correct decisions, a *d'* of .24 in mean (*d'* of .28 for short SOAs and of .20 for longer SOAs). This *d'* was significantly greater than zero [t(8)=4.12; p<.005]. Figure 4.5 illustrates the effect the prime has on word-completion in the recognition task.

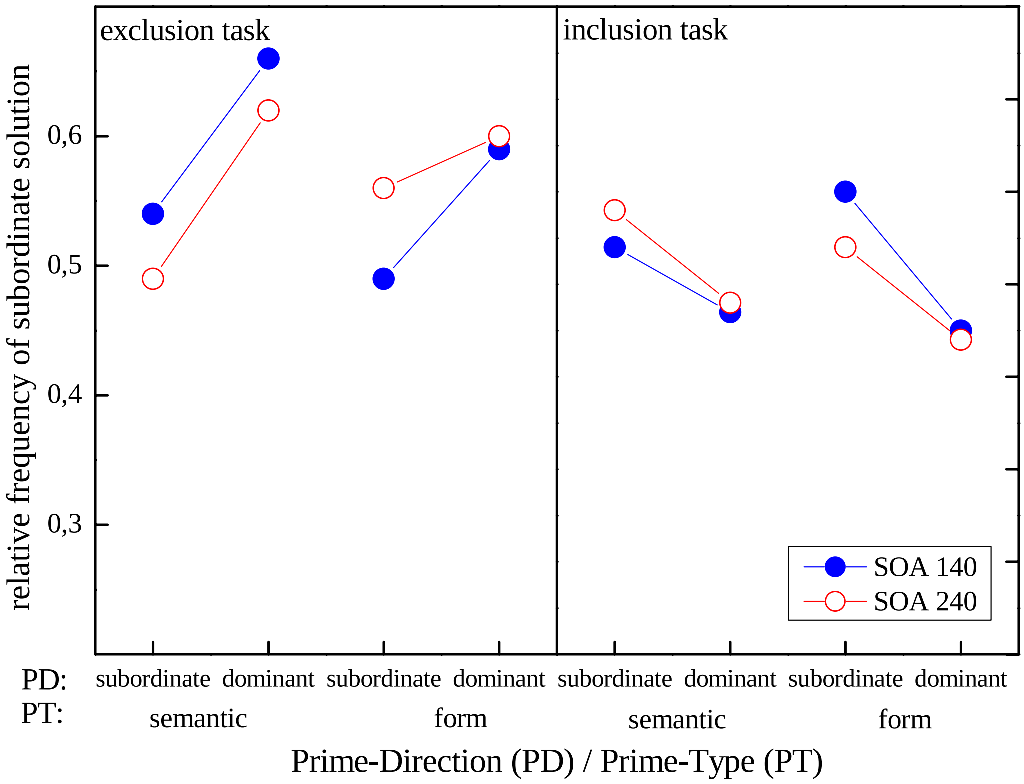

Figure 4.5: Relative frequencies of the subordinate solution in the prime recognition task as a function of Prime-Direction, Prime-Type, task (inclusion, exclusion), and SOA.

4.3 Discussion

Experiment 3 again showed form and semantic priming in the word-completion task, even with randomly assigned prime-target pairs. The results were fully comparable to those in Experiments 2a and 2b, where the same prime-target assignment was repeated throughout the experiment. Thus the present effect is not based on long-living activation, which grows over blocks. This was also obvious in the previous experiments, because all effects were observed in the first block already.

Additional analyses ruled out the possibility that priming was influenced by effects of word material due to uncontrolled word-frequency and solution-frequency effects. The item-analysis showed priming for most of the targets, not just for some of them. Solutions dominance in the pretest did not modulate priming, which shows even for infrequent, as for more frequent used solutions. Priming was observed not only for those word-pairs which were nearly equally often given as solutions. It can be deduced that the underlying mechanism can trigger subordinate as well as dominant solutions, and that even rare produced solutions become more probable when activated by their corresponding prime. However, some subordinate solutions were never produced, neither when primed nor further inhibited, as the item-analysis showed.

The frequency of a solution-word in everyday-language correlated with its dominance in the completion task. However, word-frequency did not determine the dominance of a solution; the less frequent of the two words could be the dominant solution. This suggests that word-frequency is only one of several possible variables which play a role in word-completion. The remaining letters may act as a stronger cue for one of the two words. E.g. the gap word ‘S_iel’ could be completed as ‘Spiel’ or ‘Stiel’. Although ‘Spiel’ is the more frequent of the two words (frequency index of 7 for ‘Spiel’ vs. 15 for ‘Stiel’), it was the subordinate solution (spontaneous frequency of .17 in pretest). Priming was however observed in both cases: when dominant solutions were also the higher frequent, as when dominant solutions were the less frequent words.

The recognition task showed the same pattern of results as Experiments 2a and 2b: An effect of the prime in the recognition task, which cannot clearly be assigned to conscious or automatic processes. Reducing mask-duration did not lead to an increase of solution-priming; therefore the data are not discussed further here. To clarify this issue the following chapters will focus on a different prime recognition task.

To summarize, priming occurred independently of word-frequency and availability of solution. Hence the underlying mechanism must operate such that solutions are easier to retrieve, independently of their preactivation (determined for example by frequency). This mechanism works fast, even when the prime word is excluded from awareness by strong masking.

5. Experiment 4: Separating direct from indirect effects on prime recognition

The preceding experiments showed that the solution of a word-fragment can be facilitated or impeded by masked words that are semantically or formal related. Priming occurred under masking, although it is unclear whether the observed effects were completely unconscious. In Experiment 2a, prime recognition performance suggested that participants could in fact make conscious use of the masked prime. The possibility that automatic effects triggered the response selection in the recognition task in a similar way as in the priming session still holds as an alternative explanation.

To clear up this question, a different prime recognition task was used for probing if primes were really invisible. The main problem of the earlier recognition task was that automatic and controlled effects were not clearly separable. If the prime activated its solution, this could have been used in the prime recognition as well. A more suitable task should hold the activation for one of the two solutions constant, and force participants to make direct use of prime information in the recognition task. The recognition task used now presented both primes related to one solution at the end of each trial, and forced participants to decide between them. Because both words were related to one solution, activation of a solution could no longer be used to solve prime recognition.

If the results so far are caused by partial visibility of the prime, this should clearly manifest in the following, as the chosen prime recognition task is feasible on the basis of simple visual feature comparison. If the new task reveals chance performance in the decision between the two primes, this provides strong evidence for the interpretation that automatic effects affected the former recognition task. The prediction is that a related prime enhances the probability of a solution, and that this influence occurs in the absence of participant's ability to read or discriminate the prime words.

5.1 Methods

Participants. Eighteen students (6 male) from the University of Braunschweig, age 18-40 years (mean 24.8) were tested in two one hour sessions each. All were native German speakers, and took part for course credit. None had participated in one of the preceding experiments.

Stimuli, design and procedure of the priming task all were identical to Experiment 3.

Recognition task. Prime awareness was assessed in the second session. Participants were informed about the occurrence and the structure of the primes, and instructed to focus on them rather then on the gap-words. The same stimuli and the exact same stimulus situation as in the word-generation task were used. Additionally, at the end of each trial, both the semantic and the form prime were presented until response occurred, one of which had actually been present on the current trial; both were related with the same solution. The order of events is illustrated in Figure 5.1.

The task was forced-choice recognition of the masked prime. Participants were instructed to decide which of two alternatives had been present on the trial. They were informed that the words were both related to the same solution of the gap-word, and that one of them had actually been presented.

The rationale for having the participant decide between two alternatives that both correspond to the same solution is as follows: Which gap word solution comes to mind during prime recognition, this cannot support, in backward fashion, any decision about the prime's identity, simply because both alternatives relate to the same solution, whether this was implicitly produced or not.

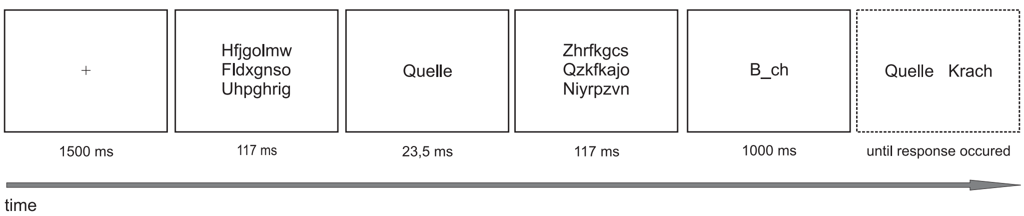

Figure 5.1: Trial structure in recognition task.

Data analysis. Arc-sine transformed solution frequencies were subjected to a repeated-measures ANOVA with Prime-Direction (dominant, subordinate), Prime-Type (semantic, form), SOA (140, 240 ms), and Block (1-4) as factors. An additional ANOVA was performed with recognition performance as between subject factor. Participants were categorized into high and low performers according to their performance in the recognition task. This factor was entered the ANOVA to control if priming was higher for those participants with higher recognition performance.

5.2 Results

Relative frequencies. Primes affected which solution was given. Figure 5.2 presents the solution frequencies as a function of Prime-Direction, Prime-Type, and Block. The ordinate gives the frequency of the subordinate solution.

Compared to the alternative, both subordinate and dominant solutions were given more frequently when preceded by their respective prime. Semantic primes made the subordinate solution more likely (.31 to .35), form primes had about the same impact (.30 to .35). These effects were small but reliable [Prime-Direction: $F(1,17)=7.48$; $p<.05$], with no difference in the impact of semantic and form primes [Prime-Type: $F(1,17)=.09$, $p=.769$; Prime-Direction x Prime-Type: $F(1,17)=.44$, $p=.725$].

Priming effects were present from the first target presentation on. Block accounted for no additional variance [$F(3,51)=.15$; $p=.908$], nor did it interact with Prime-Direction [$F(3,51)=.44$; $p=.725$] or Prime-Type [$F(3,51)=1.31$, $p=.283$]. None of the interactions including Block were reliable. Additionally, the effect of Prime-Direction was reliable when calculated on the data of the first block solely [Prime-Direction: $F(1,17)=11.21$; $p<.005$], with no difference in the impact of semantic and form primes [Prime-Type: $F(1,17)=2.05$, $p=.171$; Prime-Direction x Prime-Type: $F(1,17)=1.14$, $p=.301$].

Inspection of the data suggests that priming of both form and semantic primes was stronger on short-SOA (140 ms) trials (see figure 5.3)., but this was not backed by statistical analysis [Prime-Direction x SOA: $F(1,17)=3.26$; $p=.089$;

Prime-Type x SOA: F(1,17)=.43, p=.523; Prime-Direction x Prime-Type x SOA: F(1,17)=.09, p=.775]. All other interactions involving SOA turned out non-significant.

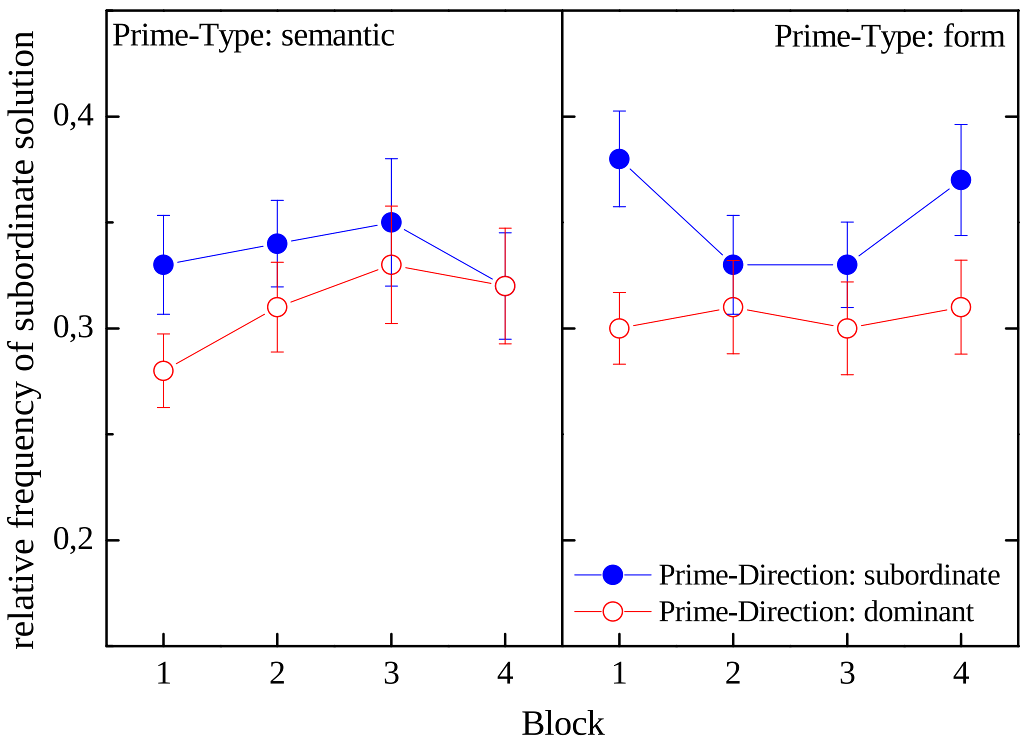

Figure 5.2: Frequency of the subordinate solution as a function of Prime-Direction, Prime-Type and Block. Note that the semantic priming effect is already present in the first block, and reduces with repetition. This trend rejects a repetition-based explanation of priming.

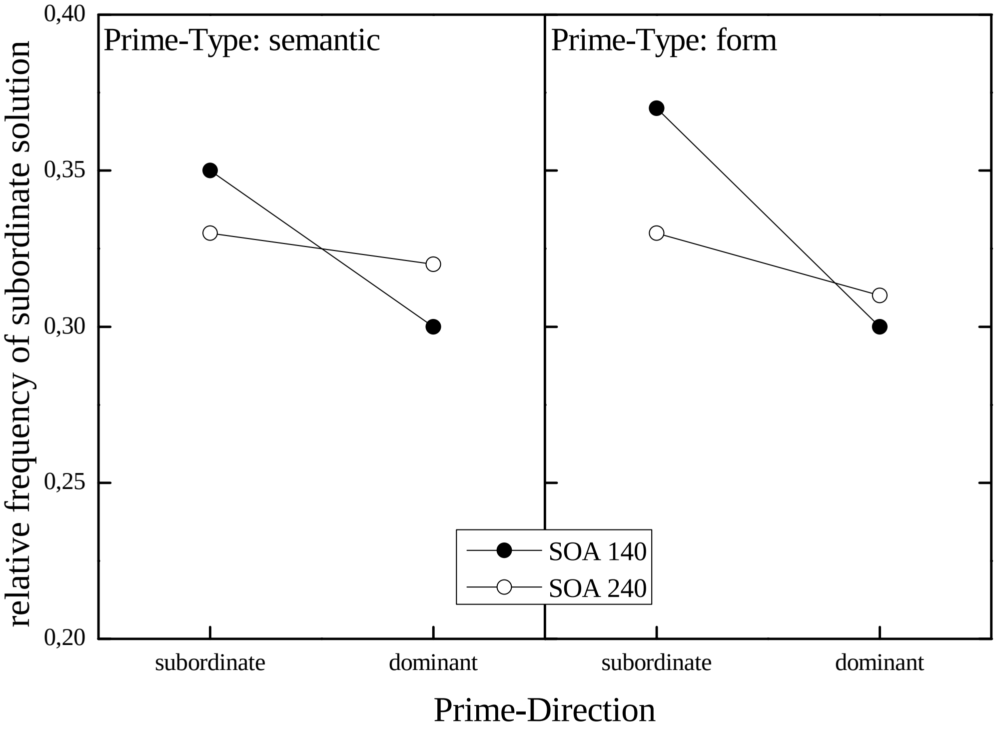

Figure 5.3: Prime influence on producing the subordinate solution as a function of SOA.

Prime recognition., Recognition performance was at chance level, with 51 percent correct and 49 percent incorrect choices. Across conditions and participants, mean *d'* was .05. (Table 5.1 presents the recognition data per subject and condition). Mean *d'* did not significantly exceed zero [t(17)=1.42; p=.088, one-sided]. Recognition *d'* equalled .09 for semantic primes, and .01 for form primes, which corresponds to 52 percent correct decisions in both cases (due to more false alarms for form primes). The difference in recognition performance between the two types of prime was not reliable [Prime-Type: F(1,17)=1.97; p=.178]; nor were there any effects of SOA [main: F(1,17)=.32; p=.577; Prime-Type x SOA: F(1,17)=.008; p=.932].

Table 5.1: Individual data of the prime recognition task. For each participant, the according percent correct and *d'* in mean and separately for semantic and form-primes are given.

participant	% correct	*d'*	*d'* semantic prime	*d'* form prime
1	51	.04	-.04	.12
2	55	.26	.32	.20
3	55	.17	.40	-.06
4	48	-.09	-.03	-.15
5	53	.15	.14	.17
6	50	.08	.31	-.15
7	53	.10	.24	-.04
8	54	.20	.26	.14
9	49	-.06	-.06	-.06
10	54	.21	.13	.30
11	52	.09	.10	.08
12	48	-.16	.10	-.43
13	49	-.05	-.16	.07
14	53	.13	.19	.07
15	55	.23	.19	.28
16	47	-.16	-.19	-.14
17	49	-.07	-.18	.04
18	47	-.19	-.11	-.27
mean (sd)	51(3)	.05(.15)	.09(.19)	.01(.19)

Recognition performance varied appreciably across participants (*d'* from -.19 to .26, corresponding to 47 to 55 percent correct, respectively). To rule out that solution priming was due to above-chance prime recognition for some participants, I subdivided the sample into groups of high and low performers. With Group as an additional factor, the ANOVA showed no interaction between Group and Prime-Direction [$F(1,16)=0.18$; $p=.673$]. Evidently, prime-recognition performance was unrelated to the amount of solution priming.

5.3 Discussion

The findings of Experiment 4 replicated the effects found so far. Related primes biased choice of the corresponding solution. This effect did not change with SOA, although a trend was observed for weaker priming with longer SOA, an observation in line with Greenwald et al. (1996), who showed that subliminal semantic priming, contrary to supraliminal priming, attenuated with longer SOAs.

Priming was fully present right from the first block on and could even be reversed in subsequent blocks, as both solutions could be primed in the course of the experiment. Effects were smaller than in Experiment 1, where they were calculated relative to a neutral prime condition. Here and in Experiment 3, priming was assessed by directly comparing the probability of a particular solution when preceded by its corresponding primes to that of the alternative solution. Both solutions could be primed in the course of the experiment, so competing activations might have attenuated each other. Accordingly, a reduction of priming in the last block (for form primes in Experiment 3 and semantic primes in the current Experiment 4) was observed. Thus, although repeating the same target under different prime-conditions has weakened priming probably, the important finding is that priming for unrepeated prime-target pairs existed in the first block already.

The recognition task asked participants whether the semantic or the form prime for one solution had actually been present on the trial. This allows inferring the masked prime if word fragments are recognized, even if the whole word remained unaware. However, prime words could not be recognized better than chance, which shows that fragment recognition played little role. Grouping participants into high and low performers showed that recognition performance was unrelated to the amount of priming (see Kiefer, 2002, for a similar finding).

Taken together, the present findings suggest that masking was efficient, and that the effects observed in the recognition task introduced in Experiment 2a and 2b were probably due to automatic effects of the primes. The new task was easier for the participants, as it allowed using a simple feature comparison to resolve it. Still, performance was close to chance and uncorrelated to the amount of priming, which strongly suggests that the previous results had been produced by automatic activation of the prime. This activation was no longer useful for the participants in the recognition task, because the primes to be discriminated were both related to the primed solution. This demonstrates the importance of details of the recognition task, as the inclusion-exclusion task did not separate between automatic and controlled sources of response bias.

Assuming on this inference, the observed effects in the recognition task of Experiments 2a, 2b and 3 can be interpreted as evidence for priming under in- and exclusion conditions. Priming thus seems to operate independently of response bias, because it was as well found when participants preferred one solution clearly over the other, as when participants, affected by instruction, chose both solutions equally common.

6. Experiment 5a and 5b: Contrasting subliminal with supraliminal priming

So far, it has been shown that masked primes affect fragment-completion even though they remain outside of conscious awareness. Conditions that are crucial for this effect were analyzed, like word-frequency, effects of repetition and dominance of solution. Most importantly, semantic and form priming were shown to occur under efficient masking conditions. That primes were processed unconsciously is supported by chance performance in a discrimination task. Participants were at chance level when instructed to process the primes explicitly, given that the implicit activation of the prime was not appropriable in the direct task. Because in the present paradigm subliminal effects on word-generation can not be based on response priming mechanisms, they must reflect automatic semantic activation.

This raises the question that forms the starting point for the current experiment. Do consciously and unconsciously processed primes have similar or even identical effects? Are priming effects distinguishable qualitatively? Is priming maximized by occasional presentation of visible primes? To answer this, primes were presented with or without masks in the next two experiments. In the following, primes presented without masks are termed visible primes.

The hypotheses were as follows: (1) Priming arises from masked and from visible primes. (2) Semantic priming occurs in visible as in masked conditions. (3) Visible form primes also affect fragment completion, when the time interval between prime- and target-onset is short, and strategic effects are probably small. Under certain conditions, strategic effects attenuate form-priming if participants generate expectancies for semantically related targets after visible primes. Neely and Kahan (2001) report that SOA durations under 500 ms make expectancy effects improbable, as is reflected in the absence of the relatedness proportion effect (Stolz & Neely, 1995).

No strong modulation of SOA on priming had been observed in the previous experiments. For this finding several explanations can be formulated: The SOAs were already maximal (as proposed by Greenwald et al., 1996). The dependent measure was insensitive to time-dependent activation. Alternatively, the build-up of activation could take longer, as observed in tasks on implicit memory (Backer-Cave, 1993), where semantic effects have been observed which last for days or even weeks. Whereas Backer-Cave showed that semantic primes can have very long-lasting effects even without conscious recollection of the words, others have shown (e.g. Greenwald, 1996) that SOA has to stay below a critical value of ca. 140-200 ms for masked semantic priming to appear.

The present Experiment 5a therefore introduced lagged prime presentations. Primes were presented one trial before their respective target-word (n-1). This was done in order to investigate whether primes presented on the preceding trial could influence target processing on the current trial.

Experiment 5b also contrasted masked with visible primes, but rather than a shifted prime presentation, a neutral prime condition was introduced. Only the subordinate solution was primed, and its probability was determined and compared when preceded by a semantic, a form, or a neutral prime.

6.1 Experiment 5a

The experiment compared subliminal with supraliminal priming of semantic and of form primes. Trials on which primes were masked were randomly mixed with trials which presented primes without masks throughout the experiment. Additionally, shifted prime presentations were introduced on half of the blocks. Shifted primes thus were presented one trial before the related target was presented. The main goal of this experiment was to show how strong supraliminal priming could become in a word completion task and to find out how robust the priming effects were to a shifted prime presentation.

6.1.1 Methods

Participants. Ten new students (four male), age 19-33 years, (mean: 24.3 years) were tested in two one hour sessions.

Stimuli, design, task and procedure were equal to Experiment 4, except for the following: Primes were either masked or visible. In the visible-prime condition an empty frame was presented instead of a mask. In blocks two and four, primes were presented one trial before their corresponding targets (shifted primes). In blocks one and three, prime-target pairs were presented on the same trial (immediate priming).

Data analysis. Prime-Direction, Prime-Type, Block, Prime-Shift, SOA and Mask were the analyzed independent variables in the ANOVA. A second ANOVA was calculated on the results of the first block solely.

Prime recognition task was equal to Experiment 4. Note that in the shifted blocks the recognition task concerned the prime on the current trial, not the n-1 prime. Participants were carefully instructed on this point.

6.1.2 Results

Relative frequencies. Overall, priming was found. Masked semantic primes again increased the frequency of their related solution. The subordinate solution was given in 35 percent when preceded by its related prime, compared to 30 percent when preceded by the prime related to the dominant solution (see Figure 6.1). On masked trials no form priming was observed. In comparison, visible primes had impact on the frequency of the subordinate solution, which was given in 42 percent after semantic primes in contrast to 26 percent after semantic primes related to the dominant solution. Likewise, the subordinate solution was given in 43 percent when preceded by visible related form primes compared to 37 percent after concurring primes.

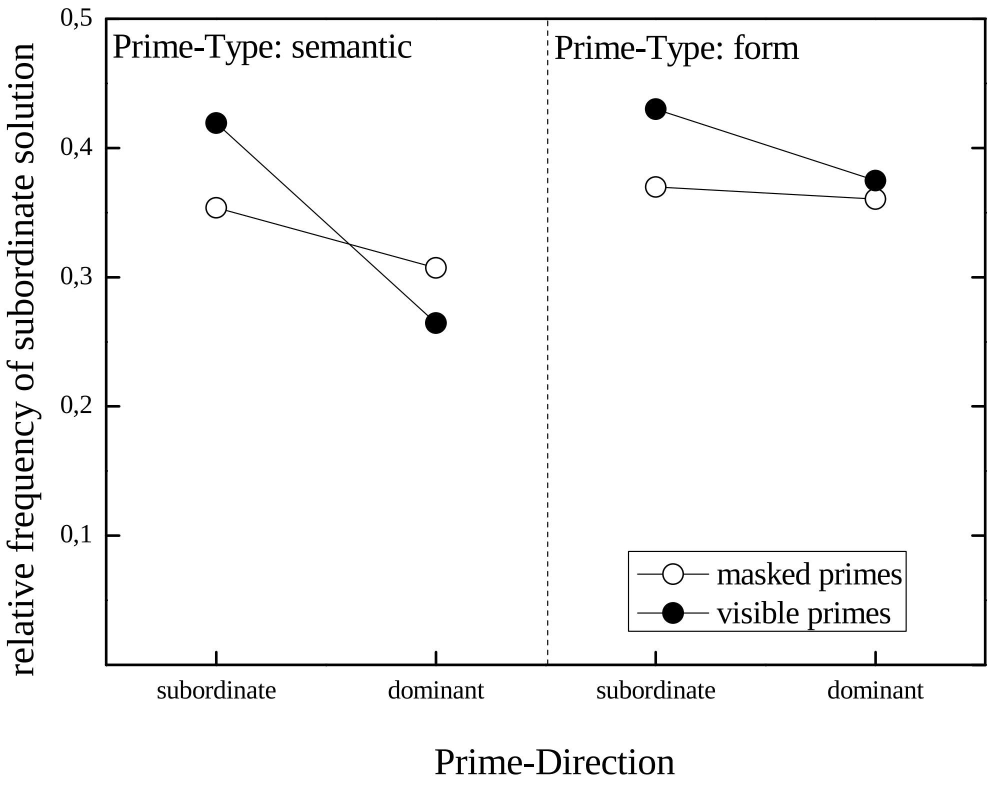

Figure 6.1: Relative frequency of the subordinate solution as a function of Prime-Direction, Prime-Type, and Mask. Note that data are collapsed across Prime-Shift.

Statistical analysis revealed reliable influence of Prime-Direction on the probability with which solutions were given [$F(1,9)=22.71$; $p <.005$]. Prime-Type had a significant main effect [$F(1,9)=14.54$; $p<.005$] too, though the interaction of both factors missed statistical significance [Prime-Direction x Prime-Type: $F(1,9)=2.35$; $p=.16$]. Prime-Direction interacted with masking [$F(1,9)=7.97$; $p<.05$]. The interaction of Prime-Direction and Prime-Shift missed significance narrowly [$F(1,9)=4.62$; $p=.06$], but was reliable when masking was included [Direction x Shift x Mask: $F(1,9)=17.1$; $p<.005$]. SOA showed no reliable influence on priming (all interactions with SOA n.s.); therefore the subsequent analyses were averaged across this factor.

The observed overall priming effect was therefore due to immediate priming of visible primes and to masked semantic priming. Both semantic and form priming effects were stronger for visible primes (Figure 6.1). Presenting primes one trial before their related target produced no clear-cut effects in blocks two and four (see Figure 6.2). For visible primes, no modulation of response selection occurred in the shifted-prime condition.

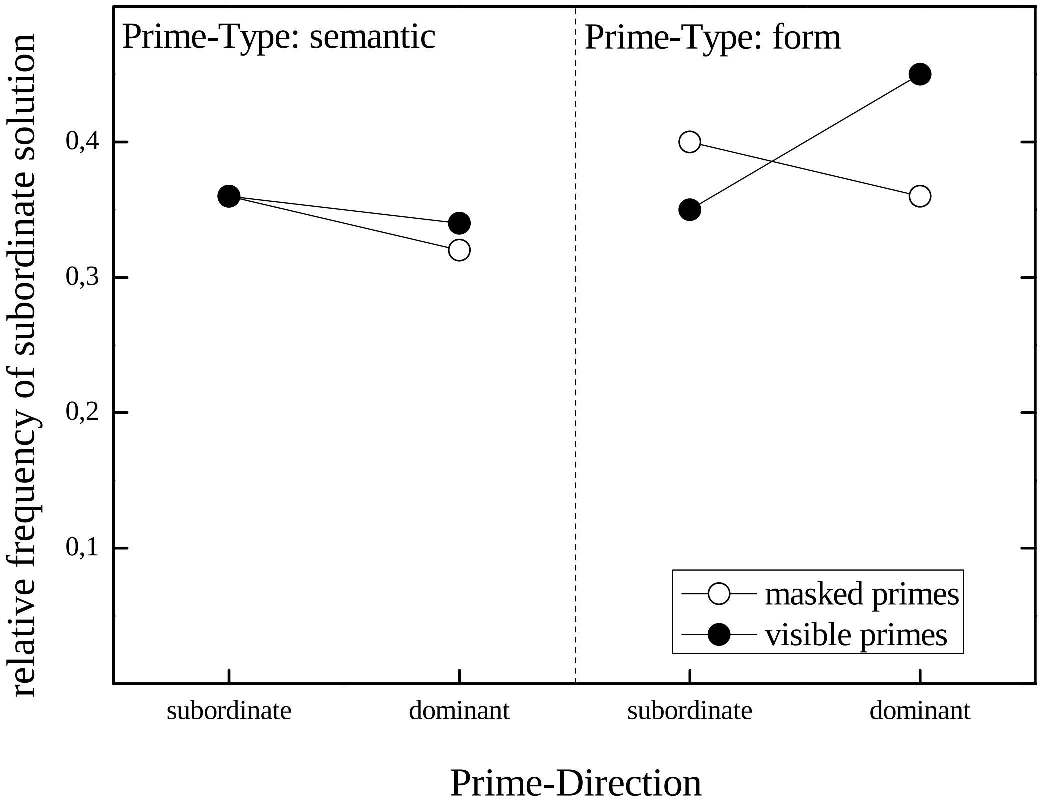

Figure 6.2: Relative frequency of the subordinate solution in the shifted-prime condition (blocks two and four) as a function of Prime-Direction and Prime-Type.

Because the shifted prime presentation produced weak or no priming, data were analyzed for the first block only. A shifted visible prime almost certainly had influence on subsequent prime processing; therefore the second unshifted block three was omitted. Figure 6.3 presents the results:

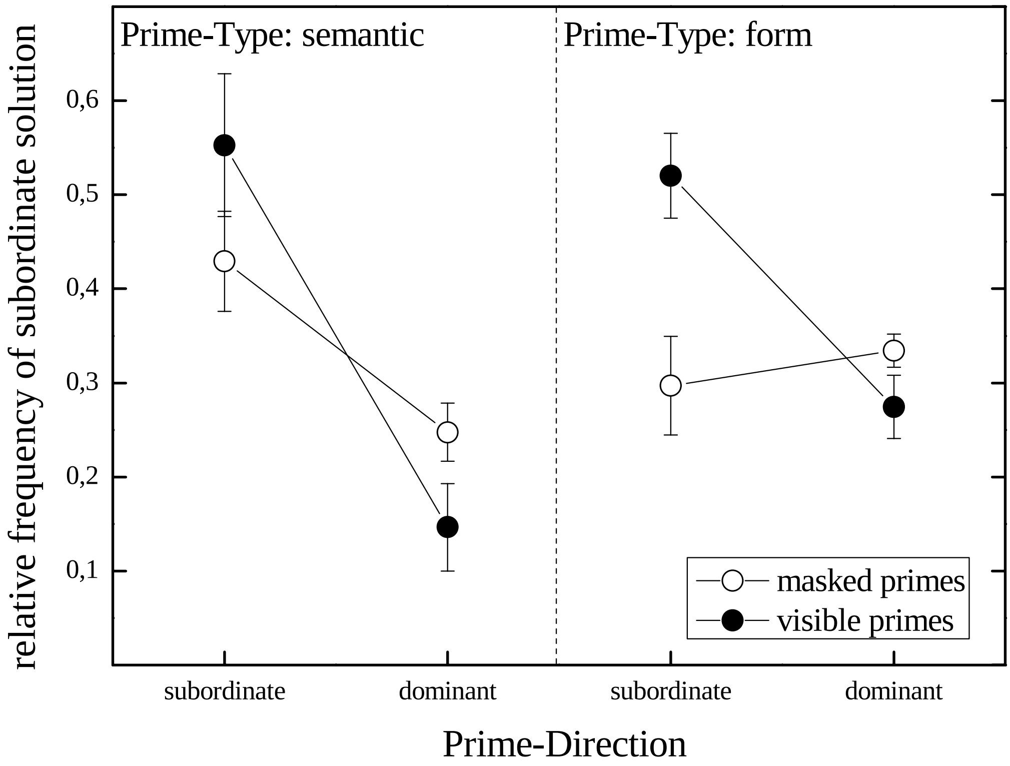

Figure 6.3: Relative frequency of subordinate solutions as a function of prime visibility, Prime-Direction and Prime-Type. Data from block 1 only (immediate priming) are shown.

Analysis of the first block revealed strong semantic priming effects for both masked and visible primes. Form priming was found for visible primes only. This observation is backed by statistical analysis: In Block 1, priming was modulated by masking [Direction x Mask: $F(1,9)=16.6$; $p<.005$], and interacted with Prime-Type [Direction x Type: $F(1,9)=6.08$; $p<.05$]. Prime-Direction showed a reliable main effect [$F(1,9)=25.53$; $p<.005$], all other interactions turned out non-significant.

Prime recognition. Due to sampling error, only data from nine out of the ten participants could be analyzed in the recognition task. Presenting primes with or without masks had a strong influence on discrimination performance. Masked primes were correctly recognized in 52.4 percent, whereas primes without masks were correctly recognized in 96.5 percent. These values correspond to *d'*-values of .09 for masked and to 1.26 for primes presented without masks.

Masked primes that were presented one trial before their corresponding targets were better recognized than primes which were presented on the same trial as their corresponding targets. In the shifted condition *d'* was 1.26 for non-masked primes, and .17 for masked primes, whereas in unshifted blocks *d'* was 1.25 for non-masked and .03 for masked primes. Shifted masked primes were better recognized in both form and semantic conditions. However these small effects were not statistically reliable. Figure 6.4 presents the according *d'* per shift and mask-condition.

Statistical analysis corroborated the impact masks had on prime recognition [$F(1,8)=123.49$; $p<.0001$]. Shifting primes one trial back did not alter performance reliably [$F(1,8)=1.44$; $p=.26$], and also the interaction with mask failed reaching significance level [Mask x Shift: $F(1,8)=.33$; $p=.58$]. None of the other interactions turned out significant either.

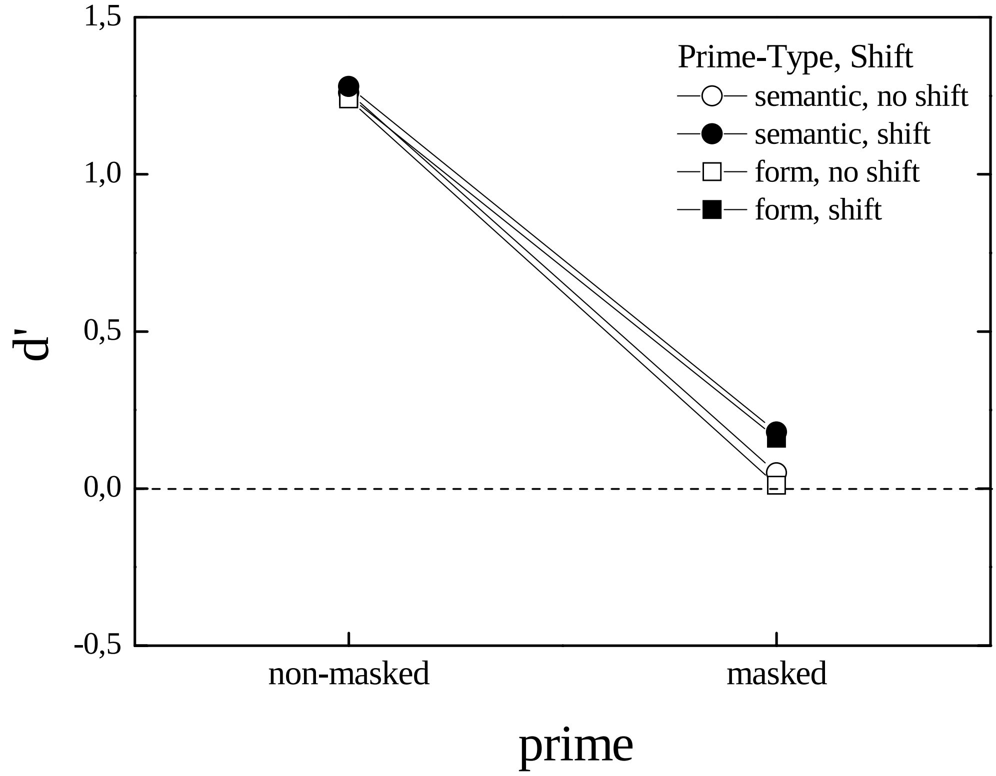

Figure 6.4: Prime recognition performance (*d'*) as a function of Prime-Masking, Shift, and Prime-Type.

6.1.3 Discussion

In Experiment 5a effects of visible primes were observed, both for form and semantic primes. This suggests that the effects observed so far of visible and invisible primes do not differ qualitatively, but quantitatively. Supraliminal priming was stronger than masked priming here, where both conditions interchanged randomly with each other, but was also stronger when compared to the amount of masked priming in the preceding experiments. With net priming of 29 percent, supraliminal semantic priming was stronger than form priming with net-priming of 21 percent. Masked priming was found for semantic but not reliably for form primes in the present experiment.

No priming of visible primes was found in blocks with a shifted prime presentation. Although masked priming might have been present, future research is needed to resolve if masked priming can be found when primes are presented one the preceding trial. However, an interesting trend was observed in the recognition task: Shifting prime presentation one trial back made prime recognition easier on masked trials. This pattern, though it failed reaching statistical significance, was observed both for form and semantic primes. This shows that the role of the target in masking is important. Although the target is irrelevant for the prime-recognition task, the target presentation has impact on prime-visibility. Therefore, the recognition task has to contain the target, and it is a mistake to omit target-stimuli in recognition tasks (e.g. Schmidt & Vorberg, 2005).

However, priming was not reliable in this experiment, as both non-masked and masked priming decreased after the first block of shifted prime-presentations. This suggests that some form of strategy shift has interfered with priming. There are at least two possibilities to explain this interference: First, unconscious as well as conscious stimulus processing depend on temporal attention, which has to be focussed on the time-window in which the prime occurs. Naccache et al. (2002) and Kiefer and Brendel (2005) have shown that when temporal attention is located away from the prime, priming reduces. As Neumann and Klotz (1994) have argued, priming depends on the direct specification of parameters, which in turn have to be integrated in an action-plan. If participants have changed their action plan and disengaged temporal attention, which is likely after some presentations of unrelated prime target pairs on the current trial, priming disappears.

Both visible and masked priming suffered from the introduction of shifted prime presentations. However the shifted presentation was a valuable experimental tool, as it made clear that a related target serves as a distractor and further inhibits conscious prime recognition. The semantic and formal relatedness of primes and targets seems to play a role in masking, additional to pattern masking mechanisms. The underlying mechanism has to operate fast and automatically, as a related gap-word has to be completed before it can induce semantic or formal interference on prime recognition.

To summarize, the present experiment showed that supraliminal priming can as well be observed in the present task. The effect of visible primes was stronger than the effect masked primes had on fragment completion. However both visible and masked primes activate their corresponding solution word, which becomes more likely as a consequence. This finding can be interpreted in terms of an activation-based account, with different activation-strengths of visible and masked primes.

6.2 Experiment 5b

Priming was observed both for masked and visible primes. Experiment 5b also compared subliminal with supraliminal priming too, but no shifted prime presentations were investigated. Rather, a neutral prime condition was introduced. This seemed necessary as primes were fully visible on half of the trials in the previous experiment, and participants could therefore use primes as valid target-predictors. Even if SOA was rather short, this might have provoked expectancy effects.

The neutral prime condition was introduced for two additional reasons: First, the neutral prime condition from Experiment 1 suffered from being a non word-stimulus; therefore the question arose, whether the comparison with a neutral condition, constructed of real unrelated words, produced similar results. Second, the finding that unrelated prime-target pairs led to higher visibility of masked primes was investigated further. If the semantic content of the gap-word served as a ‘backward mask’, neutral prime words should be recognized easier than semantic or form primes. In Experiment 5b, only the subordinate solution was primed. The prediction was increased frequency of the subordinate solution after related compared to neutral primes, with overall stronger supraliminal priming effects.

6.2.1 Methods

Participants. Eight new students (3 male), age 20-32 years, (mean: 23.3 years) were tested in two one hour sessions.

Stimuli, design, task and procedure were equal to Experiment 5a, except for the following: Only the subordinate solution was primed during the experiment, with either semantic or form primes. Additionally, 90 neutral prime-words were constructed, which were unrelated to the subordinate and the dominant solution, and showed no form overlap with both solutions (all prime and target stimuli are given in the Appendix). As in Experiment 5a, primes were presented randomly masked or without masks. Primes were presented on the same trials as their corresponding targets.

Word material pretest. To confirm that the neutral prime-words were indeed unrelated to the subordinate solution, prime-target relations were assessed by a sample of 27 new participants (mean age 26.7, range 21-58, eight male). Two sets of questionnaires were constructed, so that each subordinate solution-word was presented with its corresponding neutral and semantic prime (see Appendix). On a scale of zero (no relation) to five (very strong relation) participants judged the prime-solution pairs. Semantic primes were judged with 3.10 in mean, neutral primes were rated with 0.48. The difference in means per word was reliably different [$t(89)=41.29$; $p<.0001$]. Thus, neutral primes were indeed barely related with the solution words. The semantic relation was judged medium strong, compared to an earlier study, what might have been provoked by the title of the scale end, which was indicated with ‘very strong relation’.

Data analysis. Prime-Type (semantic, form, neutral), SOA (140, 240ms) and Mask (masked or non-masked) were the analyzed independent variables in the ANOVA. Additionally, Block (1-4) was entered a second ANOVA.

Prime recognition task. In a second session, participants were confronted with the same stimulus-situation as in the priming session, but this time the target (gap-word) was presented for 1000ms, then followed by one of the three possible primes. The task was to decide if the presented word was present on the current trial or not (yes-no prime-recognition). The last frame was presented until response occurred.

6.2.2 Results

Solution frequencies. A related prime increased the frequency of the subordinate solution compared to a neutral prime condition (.41 after a semantic-related, .42 after a form-related, .34 after a neutral prime). This priming effect was stronger for visible primes (.46 semantic, .45 form, versus .35 neutral), but was also observable in the masked condition (.36 semantic, .39 form versus .33 neutral). Figure 6.5 shows the influence Prime-Type and mask had on the frequency of the subordinate solution.

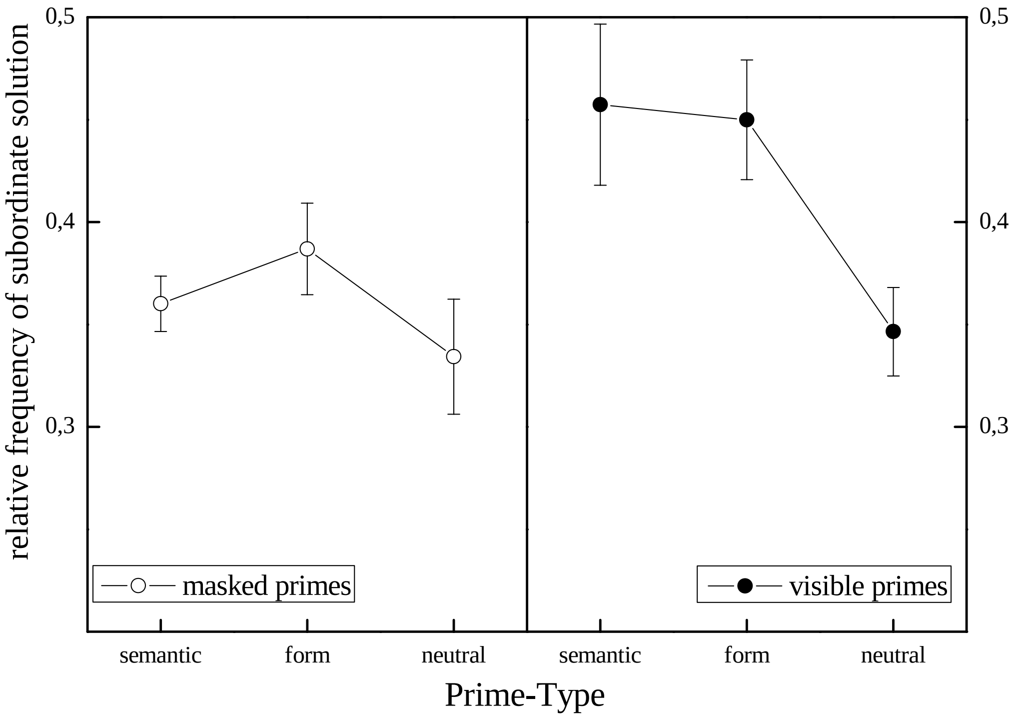

Figure 6.5: Frequency of the subordinate solution as a function of Prime-Type and Mask.

Statistical analysis confirmed that priming was reliable overall [$F(2,14)=4.79$; $p<.03$]. Both contrasts between semantic and neutral [$F(1,7)=7.36$; $p<.04$], as well as between form and neutral primes [$F(1,7)=10.38$; $p<.02$] were reliable. Presenting the primes masked or non-masked showed a main effect on the frequency of the subordinate solution [$F(1,7)=8.01$; $p<.03$], as overall proportion of subordinate solutions increased when primes, which were related in two thirds of cases, were presented non-masked (from .36 to .42, see Figure 6.6). The interaction of Prime-Type and Mask missed statistical significance [$F(2,14)=1.58$; $p=.244$]. No interaction involving SOA turned out reliable, though masked priming seemed slightly stronger on long SOA trials descriptively. All other interactions turned out non-significant too. Including block into the ANOVA led roughly to the same results, priming was reliable [$F(2,12)=4.56$; $p<.04$], but masking failed reaching statistical significance [$F(1,6)=3.27$; $p=.121$], which was probably due to the small cell allocations in this analysis. Block did not contribute to any significant interactions. Figure 6.6 presents the influence of block on priming. Inspection of the data revealed that priming did attenuate rather than strengthen with block.

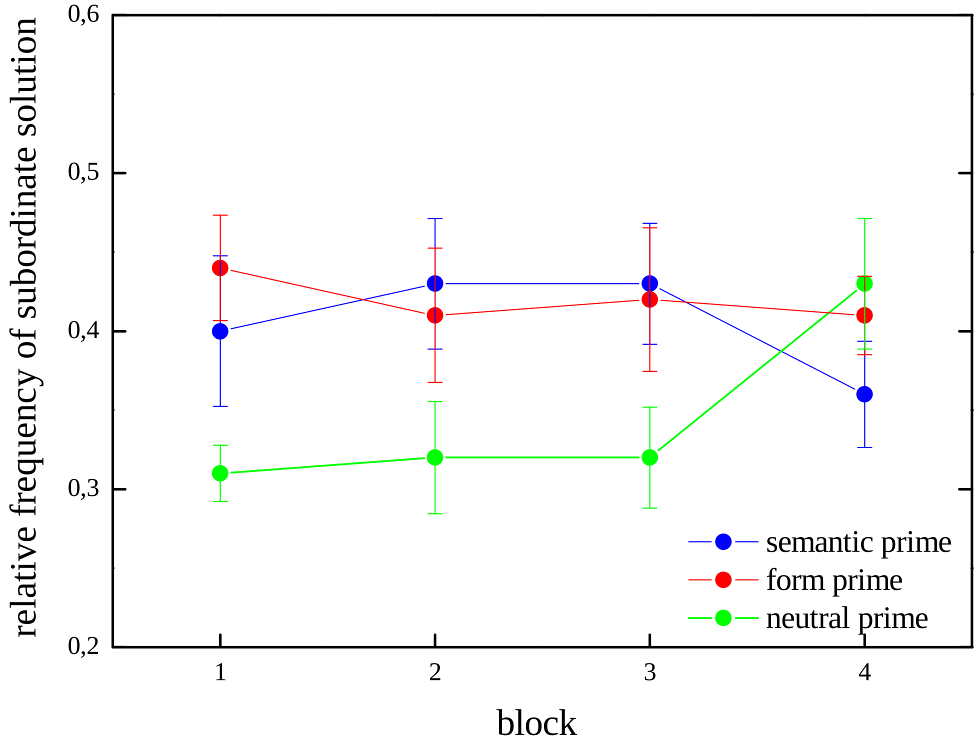

Figure 6.6: Frequency of subordinate solution as function of Prime-Type and Block. Note that the dependent variable is presented aggregated over mask-condition.

Recognition task. Because participants were able to see primes half of the time and were instructed that in two thirds of trials prime and target (the target was one of the possible primes presented at end of each trial) were dissimilar, a strong response bias developed. Participants chose the 'no'-answer in almost every masked trial, and maximized their guessing rate this way. Over all participants and trials, only 105 yes-responses were given on masked trials, compared to 1315 no-answers in this particular condition. The task was clear to the participants though, as is shown by almost perfect prime recognition performance for non-masked primes (see Figure 6.7). Therefore, recognition data were not statistically analyzed. Table 6.1 presents the according hit and false alarm rates per mask-condition and participant, showing that two of eight participants showed slightly higher hit than false alarm rates in the masked prime condition. To control that the observed semantic priming effect on masked trials was not based on the performance of these two participants, a correlation between strength of solution priming and discrimination performance was conducted, which revealed no significant relation between both factors [p=.42]. Descriptively, no influence of Prime-Type on recognition performance was observed.

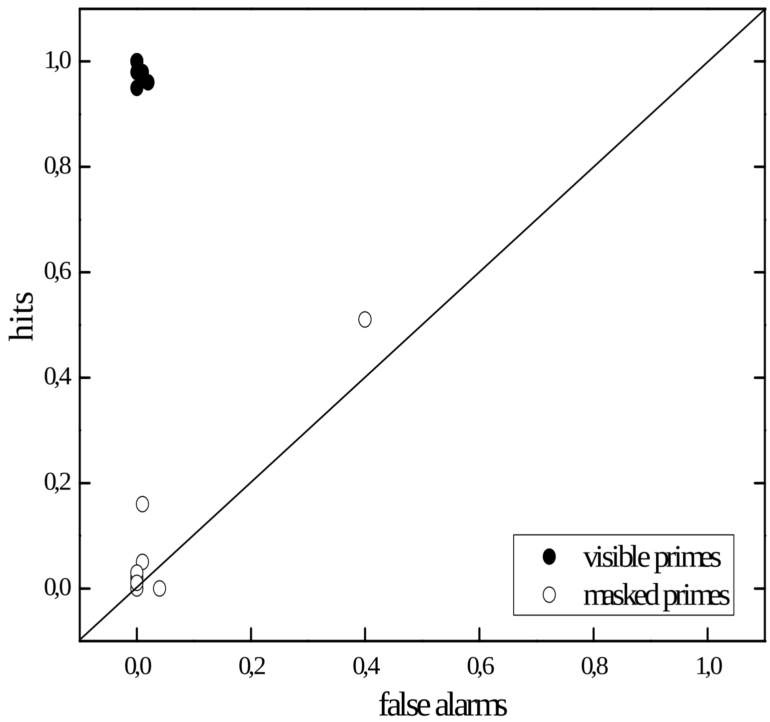

Figure 6.7: Hits and false alarms per participant and mask condition. All participants were able to recognize non-masked primes nearly perfectly.

Table 6.1: Relative hits, false alarms, misses and correct rejections per mask-condition and participant.

participant	mask-condition	hits	false alarms	misses	correct rejections
1	non-masked	.97	.01	.03	.99
1	masked	.00	.00	1.00	1.00
2	non-masked	.98	.00	.02	1.00
2	masked	.00	.04	1.00	.96
3	non-masked	1.00	.00	.00	1.00
3	masked	.16	.01	.84	.99
4	non-masked	.96	.02	.04	.98
4	masked	.01	.00	.99	1.00
5	non-masked	.95	.00	.05	1.00
5	masked	.05	.01	.95	.99
6	non-masked	.97	.01	.03	.99
6	masked	.50	.40	.50	.60
7	non-masked	.98	.01	.02	.99
7	masked	.03	.00	.97	1.00
8	non-masked	1.00	.00	.00	1.00
8	masked	.01	.00	.99	1.00

6.2.3 Discussion

The present experiment replicated the results of Experiment 1: Frequencies of the subordinate solution increased after a related compared to a neutral prime. This time, the neutral prime condition was better comparable, as it was constructed of words too. Supraliminal and subliminal priming was observed after form as well as after semantic primes. As in Experiment 5a, supraliminal priming was stronger overall and maximal after semantic primes, whereas masked priming was stronger and more stable after form primes. Although this is only a preliminary finding, future research should investigate this possible dissociation.

As far as semantic priming is concerned, not all participants showed the same pattern of results, priming after semantic primes was subject to rather large variance. This was true for visible as well as for masked primes. However, no correlation was observed, that is participants who showed little masked semantic priming nevertheless showed strong semantic priming after visible primes and vice versa. Therefore, the absence of semantic priming in one of the two conditions cannot be due to the fact that semantic relations were not suitable for these participants. The failure to find priming in some of the conditions can thus be accounted for by large error-variance in the present task.

Another observation is important: As shown in Figure 6.8, the frequency of subordinate solutions after neutral primes increased during the experiment. The frequency of subordinate solutions after neutral primes in the last block was as large as after related primes. This finding is probably due to the fact that two thirds of primes were related, and that this relation was clearly evident to the participants on half of the trials. Therefore the impact of the neutral condition is difficult to reconstruct here. Still, the introduction of a neutral condition seemed necessary in order to reduce expectancy effects in the visible condition. On the other hand, the increasing proportion of subordinate solutions during the experiment reduced priming, which was calculated in difference to the neutral condition. Therefore the priming effects observed here probably underestimate priming by both masked and visible primes. Comparing the frequencies of solutions after related with competing primes as in the preceding experiments, avoids this problem and in fact showed stronger priming.

Additionally, the results of Experiment 5b made clear that the modulations of SOA on priming found so far have to be interpreted carefully. Rather than representing a replicable pattern of results (like vanishing subliminal priming with longer SOA, in a direction of the results of Greenwald et al. 1996; or stronger semantic priming with prolonging SOA), no strong dependency of priming on SOA was found. Rather, failures to find reliable priming in some conditions were probably due to lack of power. Additionally the rather large SOA variation (100 ms step) was probably improper to trade the time-course of priming sensitively. The more robust supraliminal priming showed no dependency on SOA in the present data, future research should investigate this factor on semantic priming in word-generation using a more subtle SOA variation.

7. General discussion

The present experiments offer clear evidence for unconscious effects of prime words on the solution produced in a word-generation task. Both form and semantic primes biased the choice between two competing solutions, which both match the contextual constraints defined by the gap-word. The present paradigm was suitable to influence participants' choice of solution. This influence held for subordinate and dominant solutions, which both became more frequent after a preceding related prime.

Solution priming. The results of Experiment 1 showed that the probability of the subordinate solution can be increased by masked primes. Both form and semantic priming was observed, with form priming being stronger than semantic priming. In Experiment 2a dominant as well as subordinate solutions were primed during the experiment. Here, the priming effect was measured as the difference between the frequency of a solution when it was primed, compared to when its competing solution was primed. E.g. the subordinate solution 'Bach' was given in 38 percent of trials when preceded by its semantic prime 'Quelle', whereas it was given in 27 percent of trials only when preceded by the semantic prime 'Seite' related to the dominant solution 'Buch'. Priming was thus not gauged as the difference to a neutral condition, which is a method with several disadvantages (for a discussion on this issue see Jacobs & Grainger, 1995). In Experiments 2a and 2b a prime-recognition task was introduced, and mask-duration and SOA were varied. Both factors had no impact on solution priming. Effects of word-material were investigated in Experiment 3. It was shown that priming was independent of word-frequency and dominance of solutions. In Experiment 4 an alternative prime-recognition task was inset. The findings on prime recognition are discussed in the next paragraph. The last two experiments compared visible with masked primes. Solution priming was observed in both cases. Supraliminal was larger than subliminal priming in both experiments. Shifted primes (presented one trial before their related target) in Experiment 5a triggered no solution-priming.

Prime recognition. Two different prime-recognition tasks were introduced. In the first task, participants had to decide which solution had been primed on the current trial (inclusion), or which had not been primed (exclusion). Recognition performance was above chance-level in this task. The choice of one of the solutions was thus influenced by the prime in the recognition-task as well. However, this finding can be explained in terms of automatic activation of the prime. To separate between conscious prime recognition and automatic processes elicited by the prime, a second prime-recognition task was introduced in Experiment 4. In this task, participants had to decide which of two primes was present on the trial (2AFC). Both primes presented at the end of each trial were related to one solution. Within this design, the activation of one solution by the masked prime was of no use to solve the task, because both primes presented on the last trial were related to the same solution word. Appropriately, performance was at chance level in the second recognition task.

These findings illustrate that a task most similar to the priming task, which also used gap-word completion, was not suitable to separate between direct and indirect effects of the prime. The automatic activation of the prime had influence on performance in the prime recognition-task. The second task held activation of one solution constant, as prime recognition was realized by forced-choice between two prime-words, which were both related to one solution. Although this task was even easier, as it allowed using word-fragment information to resolve it, performance dropped at chance level. Moreover, the observed priming effects were unrelated to participants' performance, which demonstrates that the observed priming effects were not due to the use of fragments. The semantic or formal relation of prime and target showed additional influence on masking strength, as shifted unrelated primes were recognized better than related primes in Experiment 5a. Albeit preliminary, this finding indicates that target-content can distract prime-recognition (see Ramachandran & Cobb, 1995, for a similar result).

The introduced priming-task shows that the demand of Merikle and Reingold (1991), who stated that priming and recognition task should be most similar, cannot be fulfilled with all tasks that focus on complex semantic processes. As is inherent in the task, the same answer which is required on the target cannot be given on the prime, because it includes no gap. The attempt to hold the tasks most similar in fragment completion and prime-recognition intermingled direct with indirect effects of the prime, because the activation of one solution sustained and influenced participants' direct choice too. Future research could concentrate on this challenge, and should try to search for further dissociations, rather than showing priming under zero-discrimination conditions (as suggested in a recent paper by Schmidt & Vorberg, in press).

The results hint at two possible dissociations: Masked priming was stronger for form than for semantic primes, whereas non-masked priming was observed to be strongest in the semantic condition. This pattern was replicable across experiments. Delayed priming effects of shifted primes were observable on masked but not on non-masked trials. However, this finding is only a preliminary one.

Chapter 4 focussed on factors, which might have interacted with priming, like word-frequency and dominance of solutions. The results support that masked semantic and form priming are independent of frequency and dominance differences, and show that priming was not triggered by only a few word pairs. An open question concerns the difference between semantically related and associated prime-target pairs. The present word-set consisted of mostly semantically related pairs. It would be interesting to compare associated but not semantically related prime-target pairs with semantically related pairs, as different findings are reported in the literature. Whereas some authors demonstrated that semantic priming starts earlier than associative priming (Frenck-Mestre & Bueno, 1999) and that semantic priming is found up to a certain SOA only (Greenwald et al., 1996); others reported very long-lasting semantic priming effects (Backer-Cave, 1997). It is difficult, however, to construct associated prime-target pairs which are not semantically related, and some authors even suggest that the separation of both is not possible, as they are naturally confounded (Thompson-Schill, Kurtz, & Gabrieli, 1998). Some authors (e.g. Shelton & Martin, 1992) did not adequately equate semantic similarity between associated and unassociated word pairs. In their study, which focused on associates, semantic relatedness was also present (e.g. "hill-mountain", "blanket-sheet") but was not controlled or matched in comparison to unassociated prime-target pairs.

Fragment completion was chosen as a task to rebut several objections put in the field against subliminal semantic priming. The major objections against subliminal semantic priming are explanations in terms of partial visibility of primes, a sublexical locus of the effects observed, and response priming mechanisms at the heart of the effect. In addition, it is often criticized that the tasks introduced in the field do not really tap semantic processing. The effects observed for semantic primes in the present experiments can neither be accounted for by response priming mechanisms nor by partial awareness of the prime words or their fragments, and must therefore reflect genuine semantic activation without awareness.

Responses priming mechanisms, based on known stimulus-response mappings, can be ruled out as essential for the observed effects, because the two response alternatives changed from trial to trial and were unpredictable before the gap-word appeared. As stated above, partial prime awareness can also be excluded as explanation because conscious recognition was almost at chance level. Even more important, net priming did not correlate with recognition level across participants.

Amazingly, priming changed little with successive target presentation. Effects were just as large on the first as on later occurrences of a gap-word and even decreased with subsequent replications in some of the present experiments, when either of the competing solution was primed in the course of the experiment (Experiment 3 and 4), or when one solution was primed in the major part of trials (Experiment 5b). Repeating prime-target assignments did not lead to increased priming in subsequent blocks (Experiment 2a and 2b). Moreover, priming was observed from the first prime-target presentation on. Because targets were maximally repeated three times in the present experiments, the objections by Kouider and Dupoux (2004), that subliminal effects may be artefacts arising from massive repetition of primes, particularly so when prime words also occur as targets, is not of relevance.

Hutchison et al. (2004) showed that, as sublexical activation is confounded with semantic relation when repetition priming is investigated in word-stem completions, priming effects can be accounted for solely by the sublexical route of influence. When “bake” facilitates the response to “cake”, this might be due to semantic priming, but the sharing of the letter string “_ake” could also speed up processing of individual letters or their combination, prior to access of word meaning in the mental lexicon. Because of this confound of word-form and semantics, the present experiments all contrasted form and semantic primes with each other. Activation of sublexical information obviously did play a role in form priming, as evidenced by the boosting of the subordinate solution by masked form primes in the present experiments. However this cannot account for the effects of the semantic primes, which shared few letters with the solution words.

A final criticism often invoked against the existence of genuine subliminal semantic priming was about the tasks introduced. The major part of tasks in semantic priming research used lexical decisions, naming and categorizations, and measured response time differences. Bueno and Frenck-Mestre (2001) proposed that semantic processing should be investigated with tasks that really charge semantic processing. Word generation certainly does, and is likely to involve more complex processes than many of the tasks used previously.

The present results corroborate findings (Debner & Jacoby, 1994) obtained with the process-dissociation procedure under divided attention, and analogous findings in lexical decision, categorization, and naming, which have revealed either semantic priming (Greenwald et al., 1996; Draine & Greenwald, 1998; Abrams et al., 2002; Kiefer, 2002) or implicit phonological processing (Rueckl & Mathew, 1999). The body of evidence for the existence of genuine semantic priming without awareness thus has become more secure.

It can be concluded that unconscious processing involves more than facilitation or inhibition of prepared motor responses. Subliminal activation also includes automatic activation of orthographical, phonological, and semantic information of written words. Strong priming from orthographically and phonologically related prime words was found which was at least as large as effects due to semantic primes. This finding agrees with the idea of parallel activation of separable neural modules, which represent subsystems for different language attributes like word form and meaning (e.g., Schacter, 1992). However, that form priming was found to be stronger than semantic priming might reflect just greater variability in semantic as compared to form relations, for which individual associations and learned relations are less important.

The main contribution of the present research clearly is in demonstrating, with a new technique, that word-generation can be affected by the form and semantic content of written subliminal words. It was shown that these subliminal effects are not due to direct stimulus-response mappings developed within the experiment, but truly reflect the activation of semantic and form network-representations in the human brain. The present data can be taken as further evidence for models that include a fast acting, pre-conscious process in language production.

Subliminal semantic processing is likely to play a role in reading too, where parafoveal processing facilitates reading (Rayner, Well, & Pollatsek, 1980). Additionally, the effect of stimuli which were not consciously represented in patients after certain brain lesions (e.g. Blindsight, see Stoerig & Cowey, 1992), possibly relies on a fast activation with quite similar mechanisms involved as the effects reported here. Necessarily, showing subliminal semantic activation using methods other than masked priming would be conducive to support generalizations of the found effects. The present findings are able to show that genuine subliminal semantic activation generalizes to tasks as complex as fragment-completion.

The aim of the present work was not to discriminate between concurring models on the field of semantic priming or language production. Rather, the experiments presented here show that the phenomenon of masked semantic priming is based on automatic activation of word meanings, which has the potential to affect word-generation in a fragment completion task.

8. References

Abrams, R. L., Klinger, M. R., & Greenwald, A. G. (2002). Subliminal words activate semantic categories (not automated motor responses). *Psychonomic Bulletin & Review,* 9, 100-106.

Anderson, J. R. (1983). *The architecture of cognition.* Cambridge, MA: Harvard University Press.

Bentin, S: McCarthy, G., and Wood, C. C. (1985). Event-related potentials, lexical decision, and semantic priming. *Electroencephalography and Clinical Neurophysiology*, 60, 343–355.

Backer-Cave, C. B. (1997). Very long-lasting priming in picture naming. *Psychological Science,* 8, 322-325.

Breitmeyer, B.G. (1984). *Visual masking: An integrative approach.* Oxford, England: Oxford University Press.

Brown, C. M., & Hagoort, P. (1993). The processing nature of the N400: evidence from masked priming. *Journal of Cognitive Neuroscience*, 5, 33-44.

Bueno, S., & Frenck-Mestre, C. (2001). Rapid activation of the lexicon: a further investigation with behavioral and computational results. *Brain and Language,* 81, 120–130.

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review,* 82, 407-428.

Copland, D. A., de Zubicaray, G., I., McMahon, K., Wilson, S. J., Eastburn, M., & Chenery, H. J. (2003). Brain activity during automatic semantic priming revealed by event-related functional magnetic resonance imaging. *NeuroImage*, 20, 302-310.

Cree, G. S., McRae, K., & McNorgan, C. (1999). An attractor model of lexical conceptual processing: Simulating semantic priming. *Cognitive Science*, *23*, 371-414.

Damian, M. F. (2001). Congruity effects evoked by subliminally presented primes: automaticity rather than semantic processing. *Journal of Experimental Psychology: Human Perception and Performance,* 27, 154-165.

Debner, J. A., & Jacoby, L. L. (1994). Unconscious perception: Attention, awareness, and control. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 20, 304-3137.

Deacon, D., Dynowska, A., Ritter. W., & Grose-Fifer, J. (2004). Repetition and semantic priming of nonwords: Implications for theories of N400 and word recognition. *Psychophysiology*, 41, 60–74.

Dehaene, S., Naccache, L., Le Clec´H, G., Koechlin, E., Mueller, M., Deahaene-Lambertz, G., van de Moortele, P.-F., & Le Bihan, D. (1998). Imaging unconscious semantic priming. *Nature*, 395, 597-600.

Dehaene, S., Naccache, L., Cohen, L., LeBihan, D., Mangin, J. F., Poline, J. B., and Rivière, D. (2001). Cerebral mechanisms of word masking and unconscious repetition priming. *Nature Neuroscience*, 4, 752-758.

Dehaene, S., Jobert, A., Naccache, L., Ciuciu, P., Poline, J.-B., Le Bihan, D., & Cohen, L. (2004). Letter binding and invariant recognition of masked words. *Psychological Science,* 15, 307-313.

Donchin, E., (1979). Event-related potentials: A tool in the study of human information processing. In Begleiter, H., (Hrsg.). *Evoked brain potentials and behavior.* New York: Plenum Press.

Draine, S. C. & Greenwald, A. G. (1998). Replicable unconscious semantic priming. *Journal of Experimental Psychology: General,* 127, 286-303.

Enns, J. T. & Di Lollo, V. (2000). What' s new in visual masking? *Trends in Cognitive Sciences*, 9, 345 – 352.

Forster, K., Booker, J., Schacter, D. L., & Davis, C. (1990). Masked repetition priming: Lexical activation or novel memory trace? *Bulletin of the Psychonomic society*, 28, 341-345.

Friederici, A. D., Hanhe, A., & Mecklinger, A. (1996). Temporal structure of synaptic parsing: Early and late event-related brain potential effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 22, 1219-1248.

Frenck-Mestre, C., & Bueno, S. (1999). Semantic features and semantic categories: Differences in rapid activation of the lexicon. *Brain and Language*, 68, 199-204.

Gillund, G., & Shiffrin, R. (1984). A retrieval model for both recognition and recall. *Psychological Review*, 19, 1-65.

Graf, P. & Schacter, D.L. (1985). Implicit and explicit memory for new associations in normal and amnesic subjects. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 11, 501-518.

Greenwald, A. G., Draine, S. C., & Abrams, R. L. (1996). Three cognitive markers of unconscious semantic activation. *Science*, 273, 1699-1702.

Greenwald, A. G., & Draine, S. C. (1998). Distinguishing unconscious from conscious cognition- reasonable assumption and replicable findings: Reply to Merikle and Reingold (1998) and Dosher (1998). *Journal of Experimental Psychology: General*, 127, 320-324.

Holender, D. (1992). Expectancy effects, congruity effects and the interpretation of response latency measurement. In J. Alegria, D. Holender, J. Junca de Morais & M. Radeau (Eds.), *Analytic approaches to human cognition,* pp. 351-375. Amsterdam: Elsevier.

Holender, D., & Duscherer, K. (2004). Unconscious perception: The need for a paradigm shift. *Perception & Psychophysics*, 66, 872-881.

Holcomb, P.J. (1993). Semantic priming and stimulus degradation: Implications for the role of the N400 in language processing. *Psychophysiology*. 30, 47-61.

Humphrey, N. (1974). Vision in a monkey without striate cortex: a case study. *Perception*, 3, 241-255.

Hutchison, K. A., Neely, J. H., Neill W. T., & Walker, P. B. (2004). Is unconscious priming lexical or sublexical? *Consciousness and Cognition*, 13, 512-538.

Jacobs, A. M., Grainger, J., & Ferrand, L. (1995). The incremental priming technique: A method for determining within-condition priming *effects. Perception & Psychophysics*, 57, 1101-1110.

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language*, 30, 513-541.

Jonides, J., & Mack, R. (1984). On the costs and benefit of cost and benefit. *Psychological Bulletin*, 96, 29-44.

Kiefer, M., & Spitzer, M. (2000). Time course of conscious and unconscious semantic brain activation. *Cognitive Neuroscience*, 11, 2401-2407.

Kiefer, M. (2002). The N400 is modulated by unconsciously perceived masked words: further evidence for an automatic spreading activation account of N400 priming effects. *Cognitive Brain Research,* 13, 27-39.

Kiefer, M., & Brendel, D. (in press). Attentional modulation of unconscious automatic processes: Evidence from event-related potentials in a masked priming paradigm. *Journal of Cognitive Neuroscience*.

Kinoshita, S., & Lupker, S. J. (2003) *Masked priming: State of the art*. Hove, UK: Psychology Press.

Klauer, K. C., Eder, A., Greenwald, A. G., & Abrams R. L. (in press). Priming of semantic classifications by novel subliminal prime words. *Consciousness and Cognition.*

Klinger, M. R., Burton, P. C., & Pitts, G. S. (2000). Mechanisms of unconscious priming: I. response competition, not spreading activation. *Journal of Experimental Psychology: Learning, Memory, and Cognition* ,26, 441-455.

Klotz, W. & Neumann, O. (1999). Motor activation without conscious discrimination in Metakontrast masking. *Journal of Experimental Psychology: Human Perception and Performance*, 25, 976-992.

Klotz, W. & Wolff, P. (1995). The effect of a masked stimulus on the response to the masking stimulus. *Psychological Research*, 58, 92-101.

Kouider, S., & Dupoux, E. (2004). Partial awareness creates the “illusion“ of subliminal semantic priming. *Psychological Science,* 15, 75-81.

Kroll, N., Rocha, D.A., Yonelinas, A.P., & Baynes, K. 2001. Form-specific visual priming in the left and right hemispheres. *Brain and Cognition*, 47, 564-569.

Kunde, W., Kiesel, A., & Hoffmann, J. (2003). Conscious control over the content of unconscious cognition. *Cognition. 88(2). 223-242.*

Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science,* 207, 203-205.

Lamme, V. A. F., Zipser, K, & Spekreijse, H (2003). Masking interrupts figure-ground signals in V1. *Journal of Cognitive Neuroscience*, 14, 1044-1053.

Lingnau, A., & Vorberg, D. (2005). The time course of response inhibition in masked priming. *Perception & Psychophysics*, 67, 545-557.

Lucas, M. (2000). Semantic priming without association: A meta-analytic review. *Psychonomic Bulletin & Review,* 7, 618-630.

Masson, M. E. J. (2002). Bias in masked word identification: Unconscious influence of repetition priming. *Psychological Bulletin & Review,* 9, 773-779.

Mattler, U. (2003). Priming of Mental Operations by Masked Stimuli. *Perception & Psychophysics*, 65, 167-187.

Mayes, A. R., & Gooding, P. (1989). Enhancement of word completion priming in amnesics by cueing with previously novel associates. *Neuropsychologia*, 27, 1057-72.

McNamara, T., & Altarriba, J. (1988). Depth of spreading activation revisited: Semantic mediated priming occurs in lexical decisions. *Journal of Memory and Language*, 27, 545-559.

Merikle, P.M. & Reingold, E.M. (1991). Comparing direct (explicit) and indirect (implicit) measures to study nonconscious memory. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 17, 224-233.

Meyer, D. E. & Schvaneveldt, R.W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology*, 90, 227-234.

Naccache, L., Blandin, E., & Dehaene, S. (2002). Unconscious masked priming depends on temporal attention. *Psychological Science*, 13. 416-424.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G. W. Humphreys (Eds.). *Basic processes in reading*, pp. 264-336. Hillsdale, NJ: Lawrence Erlbaum associates.

Neely, J. H., & Kahan, T. A. (2001). Is semantic activation automatic? A critical re-evaluation. In H. L. Roediger, J. S. Nairne, I. Neath, & A. M. Suprenant (Eds.). *The nature of remembering: Essays in honor of R. G. Crowder*, pp. 69-93. Washington: APA Books.

Neumann, O. (1989). Kognitive Vermittlung und direkte Parameterspezifikation. Zum Problem mentaler Repräsentation in der Wahrnehmung. *Sprache & Kognition*, 8, 32-49.

Neumann, O. & Klotz, W. (1994). Motor responses to nonreportable, masked stimuli: Where is the limit of direct parameter specification? In C. Umiltà & M Moscovitch (eds.), *Attention and Performance*, 15, pp. 123-150. Cambridge, MA: MIT Press.

Plaut, D. C. (1995). Semantic and associative priming in a distributed attractor network. In *Proceedings of the 17th Annual Conference of the cognitive society*, pp. 37-42. Hillsdale, NJ: Lawrence Erlbaum Associates.

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition: The Loyola Symposium* (pp. 55-83). Hillsdale, NJ: Erlbaum.

Quillian, M. R. (1962). A revised design for an understanding machine. *Mechanical translation*, 7, 17-29.

Radeau, M., Besson, M. , Fontenau E., & Castro, S. L. (1998). Semantic, repetition and rime priming between spoken words: behavioural and electrophysiological evidence. *Biological Psychology*, 48, 183-204.

Ramachandran, V. S. & Cobb, S. (1995). Visual attention modulates metacontrast masking. *Nature*, 373, 66-68.

Ratcliff, R., & McKoon, G. (1988). A retrieval theory of priming in memory. *Psychological Review*, 95, 385-408.

Rayner, K., Well, A. D., & Pollatsek, A. (1980). Asymmetry of the effective visual field in reading. *Perception & Psychophysics*, 27, 537-544.

Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal* Behaviour, 6, 855-863.

Roediger, & Blaxton (1987). Effects of varying modality, surface features, and retention interval on priming in word-fragment completion. *Memory & Cognition*, 15, 379-388.

Rueckl, J. G., & Mathew, S. (1999). Implicit memory for phonological processes in visual stem completion. *Memory & Cognition*, 27, 1-11.

Schacter, D. L. (1987). Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 13, 501-518.

Schacter, D.L. (1992). Priming and multiple memory systems: Perceptual mechanisms of implicit memory. *Journal of Cognitive Neuroscience*, 4, 244-256.

Schacter, D. L., Badgaiyan, R. D., & Alpert, N. M. (1999). Visual word stem completion priming within and across modalities: a PET study. *NeuroReport*, 10, 2061-2065.

Schlaghecken, G. & Eimer, M. (2002). Motor activation with and without inhibition: Evidence for a threshold mechanism in motor control. *Perception & Psychophysics*, 64, 148-162.

Schmidt, T., & Vorberg, D. (in press). Criteria for Unconscious Cognition: Three Types of Dissociation. *Perception & Psychophysics.*

Shelton, J. R.,& Martin, R. C. (1992). How semantic is automatic semantic priming? *Journal of Experimental Psychology: Learning, Memory and Cognition*, 18, 1191-1210.

Simpson, G. B. (1984). Lexical ambiguity and its role in models of word recognition. *Psychological Bulletin*, 96, 2, 316-340.

Stigler, R. (1910). Chronophotische Studien über den Umgebungskontrast. *Pflügers Archiv für die gesamte Physiologie der Menschen und der Tiere*, 134, 365-435.

Stoerig, P., & Cowey, A. (1992). Wavelength sensitivity in blindsight. *Nature*, 342, 916-918.

Squire, L. R., Shimamura, A. P., and Graf, P. (1985). Independence of recognition memory and priming effects: A neuropsychological analysis, *Journal of Experimental Psychology: Learning, Memory and Cognitio*n, 11, 37-44.

Squire, L. R. (1987). *Memory and brain.* New York: Oxford University Press.

Squires K., Wickens C., Squires N., Donchin E. (1976) The effect of stimulus sequence of the waveform of the cortical event-related potential. *Science*, 193, 1142-1146.

Stern, L., D., McNaughts-Davis, A. K., & Barker, T. R. (2003). Process dissociation using a guided procedure. *Memory & Cognition,* 31, 641-655.

Stolz, J. A. & Neely, J. H. (1995). When target degradation does and does not enhance semantic context effects in word recognition. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 21, 596-611.

Thompson-Schill, S. L., Kurtz, K. J., & Gabrieli, J. D. E (1998). Effects of semantic and associative relatedness on automatic priming. *Journal of Memory and Language*, 38, 440-458.

Tulving, E., Schacter, D. L., & Stark, H. A. (1982). Priming effects in word-fragment completion are independent of recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 8, 336-342.

Vorberg, D., Mattler, U., Heinecke, A. Schmidt, T. & Schwarzbach, J. (2003). Different time courses for visual perception and action priming. *Proceedings of the National Academy of Science*, 100, 6275-6280.

Weiskrantz, L. (1986). *Blindsight. A Case Study and Implications.* New York: Oxford University Press.

Zwitserlood, P. (1996). Form priming. *Language and Cognitive Processes, 11*, 589-596.

9. Appendix

Table 9.1: Each gap-word is given with its subordinate and dominant solution, and the according semantic, form, and neutral primes.

gap-word	solution		primes for subordinate solution		primes for dominant solution		neutral primes
	subordinate	dominant	semantic	form	semantic	form	
B_ch	Bach	Buch	Quelle	Krach	lesen	Fluch	Auto
Fr_cht	Fracht	Frucht	Schiff	Gracht	Banane	Bucht	Segel
H_nd	Hand	Hund	Finger	Tand	Katze	Schund	Wasser
Wer_	Werk	Wert	Dichter	Berg	Preis	Herd	Mutter
L_chs	Luchs	Lachs	Puma	Buchs	Fisch	Dachs	Sahne
Bi_ne	Birne	Biene	Apfel	Dirne	Honig	Kieme	Matsch
B_ut	Brut	Blut	Vogel	Ruth	Vampir	Glut	Mistel
E_sen	Essen	Eisen	kochen	Hessen	Metall	speisen	Wiese
G_eis	Greis	Gleis	Opa	Preis	Schiene	klein	Wurst
P_lz	Pelz	Pilz	Nerz	Wels	Morchel	Filz	Schrank
Sch_amm	Schwamm	Schlamm	Bürste	wann	Matsch	Lamm	Baum
K_rn	Kern	Korn	Atom	gern	Schnaps	Zorn	Haus
F_lge	Folge	Felge	Serie	Molke	Reifen	Helge	Klinke
_agel	Hagel	Nagel	Sturm	hager	Hammer	Nadel	Papier
St_rn	Stern	Stirn	Sonne	gern	Gesicht	Zwirn	Ring
Sch_le	Schale	Schule	Schüssel	Aale	Lehrer	Kuhle	Krone
Wi_kel	Wickel	Winkel	Waden	Zwickel	Dreieck	Dinkel	Kaffee
_urm	Wurm	Turm	Regen	Wurf	Schloss	Tour	Tropfen
St_hl	Stahl	Stuhl	Eisen	kahl	Tisch	Pfuhl	Kirche
Ur_n	Urin	Uran	Toilette	Putin	Atom	Kran	Blatt
Wa_l	Wall	Wahl	Schutz	Knall	Urne	kahl	Tasche
S_iel	Spiel	Stiel	Fußball	Spind	Stab	Stier	Ohr
Mie_er	Mieder	Mieter	Korsett	wieder	Wohnung	Dieter	Brille

Table 9.1 (continued)							
gap-word	solution		primes for subordinate solution		primes for dominant solution		neutral primes
	subordinate	dominant	semantic	form	semantic	form	
Mü_ze	Mütze	Münze	Schal	Pfütze	Geld	Dünste	Dach
P_st	Pest	Post	Pocken	Fest	Brief	Rost	Fenster
Sp_nner	Spanner	Spinner	Voyeur	Kammer	Irrer	Zimmer	Müller
M_nd	Mond	Mund	Sonne	wohnt	Nase	Schund	Spinne
Ne_z	Nerz	Netz	Fell	Schmerz	Fischer	Hetz	Topf
G_ng	Gong	Gang	Klang	Sarong	Schritt	Hang	Apfel
N_del	Nudel	Nadel	Pasta	Pudel	Faden	Adel	Flasche
Gr_ppe	Grippe	Gruppe	Husten	Wippe	Clique	Puppe	Schirm
_eule	Beule	Keule	Schlag	Beutel	Waffe	Kehle	Kranz
K_tte	Kutte	Kette	Mantel	Nutte	Schmuck	Wette	Deckel
R_ssel	Rassel	Rüssel	Baby	Assel	Elefant	Schlüssel	Höhle
Schl_cht	Schlucht	Schlacht	Abhang	Wucht	Kampf	Wacht	Glas
_öhre	Möhre	Röhre	Erbse	Mörder	Tunnel	Röhn	Schuh
D_ckel	Deckel	Dackel	Topf	Säckel	Hund	Wackeln	Essen
Wa_ge	Wange	Waage	Gesicht	bange	Gewicht	Trage	Vogel
Sch_uck	Schmuck	Schluck	Ring	Schmutz	trinken	Schlumpf	Mütze
_üte	Güte	Tüte	Gnade	Gürtel	Plastik	Türe	Kommode
Dor_	Dorn	Dorf	Rose	Zorn	Siedlung	Torf	Schnee
_ngel	Engel	Angel	Himmel	Bengel	Fischer	Mangel	Zeh
Gew_hr	Gewähr	Gewehr	Lotto	Währung	Flinte	schwer	Flugzeug
F_ucht	Flucht	Frucht	Ausbruch	Schlucht	Obst	Bruch	Katze
Tau_e	Taufe	Taube	Geburt	Schlaufe	Friedens	Haube	Stamm
Za_n	Zahn	Zaun	beißen	Kahn	Mauer	kaum	Fluss
B_uch	Bauch	Bruch	Nabel	Rauch	Knochen	Fluch	Busch
A_ge	Alge	Auge	Meer	Salbe	sehen	Lauge	Tafel
B_ei	Brei	Blei	Griess	frei	schwer	Kleie	Garten
_rage	Trage	Frage	Bahre	Tran	Antwort	Franse	Teufel

Table 9.1 (continued)

gap-word	solution		primes for subordinate solution		primes for dominant solution		neutral primes
	subordinate	dominant	semantic	form	semantic	form	
Bl_se	Blase	Bluse	Seifen	Nase	Hemd	Muse	Kind
Wie_e	Wiege	Wiese	Bettchen	Stiege	Rasen	Miese	Telefon
Ak_e	Akte	Akne	Büro	Nackte	Pickel	Lasagne	Wagen
_ebel	Hebel	Nebel	Rauch	Knebel	Schalter	heben	Wiege
B_rg	Burg	Berg	Ritter	Schurke	Gipfel	Zwerg	Speiche
Ade_	Ader	Adel	Blut	Kader	Baron	Nadel	Rock
L_ck	Leck	Lack	Schiff	Scheck	Farbe	Plaque	Himmel
Aa_	Aas	Aal	Geier	Frass	Fisch	Wahl	Traktor
W_nd	Wand	Wind	Haus	Tand	Sturm	Kind	Futter
Alt_r	Altar	Alter	Kirche	Basar	Jugend	Halter	Kartoffel
Zec_e	Zeche	Zecke	Kneipe	Becher	Insekt	Decke	Bauer
Lebe_	Leben	Leber	Geburt	geben	Organ	Zeder	Boden
Nor_	Norm	Nord	Regel	Form	Süd	Hort	Knospe
_öwe	Möwe	Löwe	Meer	Amöbe	Tiger	löse	Griff
Qu_lle	Qualle	Quelle	Strand	Schnalle	Fluss	Welle	Licht
Stie_	Stier	Stiel	Kampf	Tier	Griff	viel	Truhe
Bl_ck	Blick	Block	Augen	Trick	Heft	Pflock	Brot
_rust	Frust	Brust	Ärger	Frucht	stillen	Brunft	Pfeffer
B_hne	Bohne	Bühne	Schote	Zone	Theater	Sühne	Kobold
Schi_f	Schilf	Schiff	Sumpf	hilf	Segel	Riff	Waschbär
Sta_l	Stall	Stahl	Kuh	Knall	Eisen	kahl	Schnecke
_ild	Bild	Wild	Maler	bald	Rehe	Kilt	Stern
Rin_	Ring	Rind	Finger	Ding	Kuh	Wind	Mücke
_uch	Tuch	Buch	Stoff	Tour	lesen	Fluch	Trompete
G_as	Gras	Glas	grün	Grad	Fenster	Blase	Kerze
Bibe_	Bibel	Biber	Gott	Riegel	Nager	Viper	Kammer
R_hr	Ruhr	Rohr	Durchfall	Schnur	Leitung	Tor	Pinsel

Table 9.1 (continued)

gap-word	solution		primes for subordinate solution		primes for dominant solution		neutral primes
	subordinate	dominant	semantic	form	semantic	form	
Bei_	Bein	Beil	Arm	Wein	Axt	weil	Jacke
Ra_m	Raum	Rahm	Zimmer	Traum	Sahne	lahm	Zahn
Her_	Herz	Herd	Organ	Schmerz	Ofen	Wert	Farbe
_arren	Barren	Karren	Gold	Barke	Wagen	Karrenz	Fleisch
Schl_nge	Schlinge	Schlange	Lasso	Klinge	Natter	Zange	Teller
Tie_	Tief	Tier	Hoch	Mief	Vogel	Vier	Ufer
_inger	Ringer	Finger	Sumo	Rinder	Hand	Finder	Schwan
R_lle	Rille	Rolle	Kerbe	Stille	Speck	Tolle	Brücke
_usch	Tusch	Busch	Trommel	Tisch	Afrika	Buch	Sehnsucht
_uft	Duft	Luft	Parfüm	Dutt	Atem	Kluft	Herz
_atter	Gatter	Natter	Zaun	glatt	Ringel	Natur	Dichter
K_rbel	Kerbel	Kurbel	Safran	Bärbel	Dreher	Gurgel	Husten
_raut	Braut	Kraut	Hochzeit	Brauch	Gewürz	Krause	Skalpell

Table 9.2: The table shows the spontaneous frequency for each solution in the pretest, and gives the consequent classification into subordinate and dominant solutions. The classification is based on the judgments of 30 participants. The frequency number denotes the quota with which the particular solution was given first.

target number	subordinate solution	frequency in pretest	dominant solution	frequency in pretest
1	Bach	.21	Buch	.79
2	Fracht	.10	Frucht	.90
3	Hand	.14	Hund	.86
4	Werk	.14	Wert	.86
5	Luchs	.34	Lachs	.66
6	Birne	.37	Biene	.63
7	Brut	.10	Blut	.90
8	Essen	.43	Eisen	.57
9	Greis	.23	Gleis	.77
10	Pelz	.15	Pilz	.85
11	Schwamm	.20	Schlamm	.80
12	Kern	.33	Korn	.67
13	Folge	.36	Felge	.64
14	Hagel	.13	Nagel	.87
15	Stern	.32	Stirn	.68
16	Schale	.43	Schule	.57
17	Wickel	.10	Winkel	.90
18	Wurm	.39	Turm	.61
19	Stahl	.43	Stuhl	.57
20	Urin	.37	Uran	.63
21	Wall	.00	Wahl	1.00
22	Spiel	.17	Stiel	.83
23	Mieder	.21	Mieter	.79
24	Mütze	.40	Münze	.60
25	Pest	.33	Post	.67
26	Spanner	.24	Spinner	.76
27	Mond	.31	Mund	.69
28	Nerz	.10	Netz	.90
29	Gong	.28	Gang	.72
30	Nudel	.34	Nadel	.66
31	Grippe	.24	Gruppe	.76
32	Beule	.11	Keule	.89
33	Kutte	.41	Kette	.59
34	Rassel	.43	Rüssel	.57
35	Schlucht	.35	Schlacht	.65
36	Möhre	.28	Röhre	.72
37	Deckel	.34	Dackel	.66
38	Wange	.07	Waage	.93
39	Schmuck	.21	Schluck	.79
40	Güte	.01	Tüte	.99
41	Dorn	.41	Dorf	.59
42	Engel	.28	Angel	.72
43	Gewähr	.28	Gewehr	.72

Table 9.2 (continued)				
target number	subordinate solution	frequency in pretest	dominant solution	frequency in pretest
44	Flucht	.14	Frucht	.86
45	Taufe	.28	Taube	.72
46	Zahn	.45	Zaun	.55
47	Bauch	.28	Bruch	.72
48	Alge	.41	Auge	.59
49	Brei	.34	Blei	.66
50	Trage	.34	Frage	.66
51	Blase	.48	Bluse	.52
52	Wiege	.31	Wiese	.69
53	Akte	.45	Akne	.55
54	Hebel	.49	Nebel	.51
55	Burg	.24	Berg	.76
56	Ader	.31	Adel	.69
57	Leck	.07	Lack	.93
58	Aas	.00	Aal	1.00
59	Wand	.21	Wind	.79
60	Altar	.17	Alter	.83
61	Zeche	.41	Zecke	.59
62	Leben	.24	Leber	.76
63	Norm	.46	Nord	.54
64	Möwe	.07	Löwe	.93
65	Qualle	.24	Quelle	.76
66	Stier	.41	Stiel	.59
67	Blick	.34	Block	.66
68	Frust	.39	Brust	.61
69	Bohne	.38	Bühne	.62
70	Schilf	.07	Schiff	.93
71	Stall	.24	Stahl	.76
72	Bild	.37	Wild	.63
73	Ring	.24	Rind	.76
74	Tuch	.21	Buch	.79
75	Gras	.41	Glas	.59
76	Bibel	.49	Biber	.51
77	Ruhr	.29	Rohr	.71
78	Bein	.46	Beil	.54
79	Raum	.21	Rahm	.79
80	Herz	.41	Herd	.59
81	Barren	.38	Karren	.62
82	Schlinge	.34	Schlange	.66
83	Tief	.34	Tier	.66
84	Ringer	.29	Finger	.71
85	Rille	.29	Rolle	.71
86	Tusch	.07	Busch	.93
87	Duft	.49	Luft	.51
88	Gatter	.29	Natter	.71
89	Kerbel	.07	Kurbel	.93
90	Braut	.41	Kraut	.59

Table 9.3: The relatedness-ratings for each semantic and neutral prime to the subordinate solution are given. The data are based on the ratings of 27 participants on a scale from 0 (not related at all) to 5 (very strong relationship).

semantic prime	subordinate solution	rating	neutral prime	subordinate solution	rating
Quelle	Bach	3.38	Auto	Bach	.57
Schiff	Fracht	3.31	Siegel	Fracht	1.36
Finger	Hand	4.69	Wasser	Hand	.93
Dichter	Werk	3.15	Mutter	Werk	.93
Puma	Luchs	3.46	Sahne	Luchs	.14
Apfel	Birne	4.38	Matsch	Birne	3.29
Vogel	Brut	2.62	Mistel	Brut	.64
kochen	Essen	4.62	Wiese	Essen	.57
Opa	Greis	3.62	Wurst	Greis	.14
Nerz	Pelz	3.69	Schrank	Pelz	1.64
Bürste	Schwamm	2.77	Baum	Schwamm	.79
Atom	Kern	3.62	Haus	Kern	.86
Serie	Folge	3.54	Klinke	Folge	.29
Sturm	Hagel	3.15	Papier	Hagel	.50
Sonne	Stern	3.08	Ring	Stern	1.36
Schüssel	Schale	3.54	Krone	Schale	.79
Waden	Wickel	3.62	Kaffee	Wickel	.36
Regen	Wurm	3.38	Tropfen	Wurm	.57
Eisen	Stahl	3.85	Kirche	Stahl	.29
Toilette	Urin	3.77	Blatt	Urin	.64
Schutz	Wall	3.46	Tasche	Wall	.36
Fußball	Spiel	4.00	Ohr	Spiel	.79
Korsett	Mieder	3.54	Brille	Mieder	.43
Schal	Mütze	4.23	Dach	Mütze	1.08
Pocken	Pest	3.54	Fenster	Pest	.31
Voyeur	Spanner	3.85	Müller	Spanner	.57
Sonne	Mond	4.23	Spinne	Mond	.29
Fell	Nerz	3.23	Topf	Nerz	.64
Klang	Gong	3.85	Apfel	Gong	.29
Pasta	Nudel	4.31	Flasche	Nudel	.79
Husten	Grippe	4.15	Schirm	Grippe	.79
Schlag	Beule	2.62	Kranz	Beule	.86
Mantel	Kutte	3.08	Deckel	Kutte	.43
Baby	Rassel	3.46	Höhle	Rassel	.43
Abhang	Schlucht	3.23	Glas	Schlucht	.50
Erbse	Möhre	4.08	Schuh	Möhre	.07
Topf	Deckel	4.69	Essen	Deckel	1.00
Gesicht	Wange	3.54	Vogel	Wange	.43
Ring	Schmuck	3.69	Mütze	Schmuck	.50
Gnade	Güte	2.38	Kommode	Güte	.21
Rose	Dorn	3.92	Schnee	Dorn	.50
Himmel	Engel	3.92	Zeh	Engel	.21
Lotto	Gewähr	3.00	Flugzeug	Gewähr	.79
Ausbruch	Flucht	3.15	Katze	Flucht	.86

Table 9.3 (continued)

semantic prime	subordinate solution	rating	neutral prime	subordinate solution	rating
Geburt	Taufe	3.23	Stamm	Taufe	.57
beißen	Zahn	3.71	Fluss	Zahn	.15
Nabel	Bauch	3.43	Busch	Bauch	.23
Meer	Alge	3.43	Tafel	Alge	.08
Griess	Brei	4.43	Garten	Brei	.08
Bahre	Trage	3.57	Teufel	Trage	.23
Seifen	Blase	4.14	Kind	Blase	.31
Bettchen	Wiege	3.71	Telefon	Wiege	.15
Büro	Akte	3.57	Wagen	Akte	.15
Rauch	Hebel	.71	Wiege	Hebel	.23
Ritter	Burg	4.14	Speiche	Burg	.08
Blut	Ader	4.14	Rock	Ader	.15
Schiff	Leck	3.07	Himmel	Leck	.15
Geier	Aas	4.43	Traktor	Aas	.08
Haus	Wand	3.00	Futter	Wand	.15
Kirche	Altar	4.07	Kartoffel	Altar	.00
Kneipe	Zeche	3.14	Bauer	Zeche	.85
Geburt	Leben	3.71	Boden	Leben	1.38
Regel	Norm	3.29	Knospe	Norm	.00
Meer	Möwe	3.43	Griff	Möwe	.08
Strand	Qualle	3.43	Licht	Qualle	.23
Kampf	Stier	2.93	Truhe	Stier	.08
Augen	Blick	3.71	Brot	Blick	.15
Ärger	Frust	4.00	Pfeffer	Frust	.08
Schote	Bohne	3.14	Kobold	Bohne	.00
Sumpf	Schilf	3.50	Waschbär	Schilf	.46
Kuh	Stall	3.93	Schnecke	Stall	.08
Maler	Bild	3.93	Stern	Bild	1.23
Finger	Ring	3.79	Mücke	Ring	.15
Stoff	Tuch	3.21	Trompete	Tuch	.46
grün	Gras	4.43	Kerze	Gras	.08
Gott	Bibel	3.79	Kammer	Bibel	.38
Durchfall	Ruhr	2.00	Pinsel	Ruhr	.08
Arm	Bein	3.57	Jacke	Bein	.15
Zimmer	Raum	3.86	Zahn	Raum	.08
Organ	Herz	3.71	Farbe	Herz	.77
Gold	Barren	4.00	Fleisch	Barren	.08
Lasso	Schlinge	3.86	Teller	Schlinge	.00
Hoch	Tief	4.21	Ufer	Tief	1.69
Sumo	Ringer	4.07	Schwan	Ringer	.38
Kerbe	Rille	2.43	Brücke	Rille	.38
Trommel	Tusch	1.93	Sehnsucht	Tusch	.00
Parfüm	Duft	4.00	Herz	Duft	.46
Zaun	Gatter	2.93	Dichter	Gatter	.15
Safran	Kerbel	2.14	Husten	Kerbel	.46
Hochzeit	Braut	4.43	Skalpell	Braut	.08

Table 9.4: Each solution (subordinate, dominant) is given with its frequency index in everdy-language. The index denotes a frequency-class. It is given in relation to the German article ‘der‘, which is 2^ index times more frequent than the particular word. Thus small indices indicate more frequent words. The indices were taken from the thesaurus dictionary of the University of Leipzig.

target number	subordinate solution	word frequency	dominant solution	word frequency
1	Bach	10	Buch	08
2	Fracht	13	Frucht	13
3	Hand	08	Hund	10
4	Werk	08	Wert	08
5	Luchs	15	Lachs	13
6	Birne	14	Biene	15
7	Brut	14	Blut	10
8	Essen	09	Eisen	12
9	Greis	13	Gleis	13
10	Pelz	13	Pilz	13
11	Schwamm	14	Schlamm	12
12	Kern	10	Korn	13
13	Folge	08	Felge	16
14	Hagel	14	Nagel	12
15	Stern	10	Stirn	11
16	Schale	13	Schule	08
17	Wickel	17	Winkel	11
18	Wurm	13	Turm	11
19	Stahl	11	Stuhl	11
20	Urin	13	Uran	12
21	Wall	12	Wahl	08
22	Spiel	07	Stiel	15
23	Mieder	15	Mieter	09
24	Mütze	12	Münze	13
25	Pest	13	Post	09
26	Spanner	16	Spinner	14
27	Mond	11	Mund	10
28	Nerz	16	Netz	09
29	Gong	14	Gang	10
30	Nudel	16	Nadel	13
31	Grippe	12	Gruppe	08
32	Beule	15	Keule	14
33	Kutte	15	Kette	11
34	Rassel	18	Rüssel	15
35	Schlucht	13	Schlacht	11
36	Möhre	17	Röhre	13
37	Deckel	13	Dackel	14
38	Wange	13	Waage	12
39	Schmuck	11	Schluck	13
40	Güte	12	Tüte	13
41	Dorn	14	Dorf	09
42	Engel	10	Angel	13
43	Gewähr	14	Gewehr	12
44	Flucht	10	Frucht	13
45	Taufe	12	Taube	13
46	Zahn	13	Zaun	12
47	Bauch	11	Bruch	11
48	Alge	16	Auge	09
49	Brei	14	Blei	13

Table 9.4 (continued)

target number	subordinate solution	word frequency	dominant solution	word frequency
50	Trage	15	Frage	07
51	Blase	14	Bluse	14
52	Wiege	13	Wiese	11
53	Akte	12	Akne	16
54	Hebel	13	Nebel	11
55	Burg	11	Berg	10
56	Ader	14	Adel	12
57	Leck	14	Lack	13
58	Aas	15	Aal	15
59	Wand	10	Wind	09
60	Altar	12	Alter	09
61	Zeche	13	Zecke	16
62	Leben	06	Leber	12
63	Norm	12	Nord	11
64	Möwe	14	Löwe	12
65	Qualle	17	Quelle	10
66	Stier	13	Stiel	15
67	Blick	08	Block	11
68	Frust	11	Brust	10
69	Bohne	15	Bühne	08
70	Schilf	14	Schiff	10
71	Stall	12	Stahl	11
72	Bild	08	Wild	12
73	Ring	10	Rind	13
74	Tuch	12	Buch	08
75	Gras	11	Glas	10
76	Bibel	11	Biber	14
77	Ruhr	12	Rohr	12
78	Bein	11	Beil	14
79	Raum	08	Rahm	16
80	Herz	09	Herd	12
81	Barren	15	Karren	13
82	Schlinge	14	Schlange	11
83	Tief	12	Tier	10
84	Ringer	14	Finger	10
85	Rille	17	Rolle	08
86	Tusch	15	Busch	12
87	Duft	12	Luft	09
88	Gatter	16	Natter	16
89	Kerbel	18	Kurbel	15
90	Braut	11	Kraut	13